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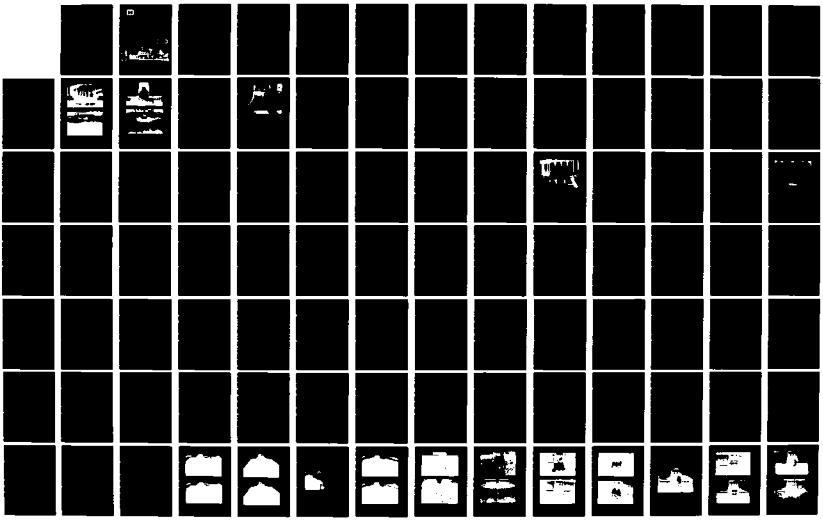

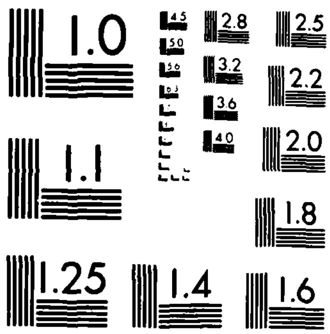
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TECHNICAL REPORT HL-83-3

POINTE COUPEE PUMPING STATION SUMP AND OUTLET STRUCTURE, UPPER POINTE COUPEE LOOP AREA, LOUISIANA

Hydraulic Model Investigation

by

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Physical models were used to evaluate the hydraulic performance of the Pointe Coupee pumping station sump and outlet structure. A sump design with umbrellas on the suction bells, converging sidewalls, and horizontal vortex suppressor beams provided satisfactory sump performance for pumps with low submergence. Approach channel modifications were found to have a negligible effect

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20. ABSTRACT (Continued).

on sump performance. A stilling basin design with baffles and divider walls was developed. Riprap sizes were determined for the outlet channel downstream from the stilling basin. With the recommended designs, satisfactory hydraulic performance was achieved for the entire range of expected discharges, sump water-surface elevations, and tailwaters.

A third model study of the Point Coupee siphon was also conducted and reported in WES Technical Report HL-82-21 dated September 1982.

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PREFACE

The model investigations of the Pointe Coupee Pumping Station pump intake (sump) and stilling basin (outlet structure) reported herein were authorized by the Office, Chief of Engineers (OCE), U.S. Army, on 14 February 1978, at the request of the U. S. Army Engineer District, New Orleans (LMN). Included in this authorization were model investigations of the pumping station siphon which are discussed in a separate report (WES TR HL-82-21).

This investigation was conducted during the period September 1979 to August 1982, in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the general supervision of N. R. Oswalt, Chief of the Spillways and Channels Branch. The project engineer for the model studies was Mr. R. R. Copeland, assisted by Mr. E. L. Jefferson. Mr. B. F. Stanfield is acknowledged for his work in constructing the models. This report was prepared by Mr. Copeland.

During the course of the study, Messrs. Cecil W. Soileau, Reynold D. Broussard, Mike Sanchez-Barbudo, James Ferris, Rober J. Guizerix, Daniel Marsalone, and Arthur Laurent of LMN; Hugh E. Wardlaw, John B. Harman, Joe Barber, John Monroe, and James Pendergrass of the Memphis District; Joe McCormick, Larry Cook, Larry Eckenrod, Roddis C. Randell, Frank Weaver, Frank Johnson, Roland J. Dubisson, and Robert I. Kaufman of the Lower Mississippi Valley Division; and John S. Robertson and Sam Powell of OCE visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with concurrent design work.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831865	cubic metres per second
Fahrenheit degrees	*	Celsius degrees or Kelvins
feet	0.3048	metres
feet of water	0.03048	kilograms per square centimetre
feet per second	0.3048	metres per second
gallons per minute	3.785412	cubic decimetres per minute
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square miles	259.0	hectares

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

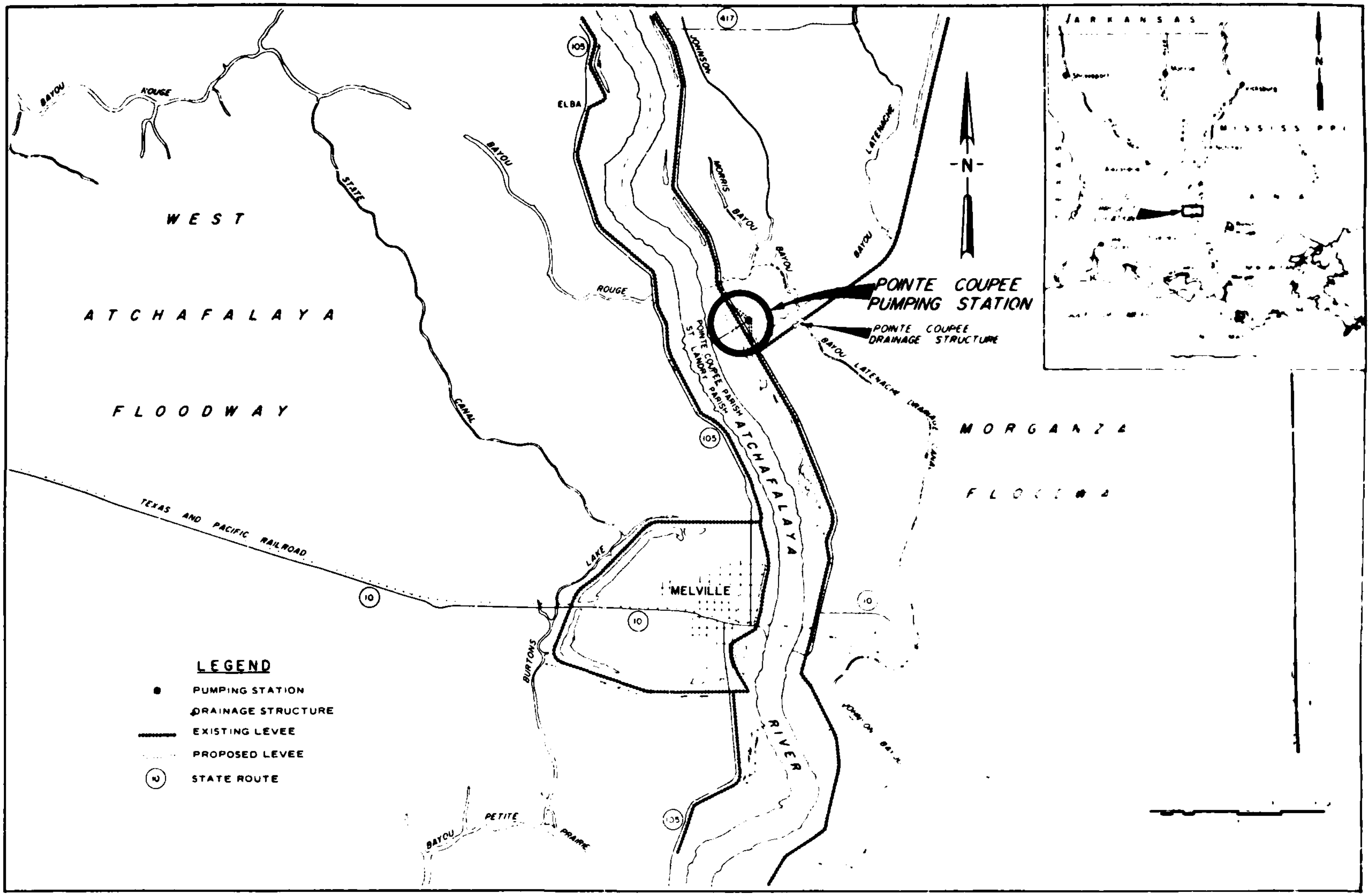


Figure 1. Location map

POINTE COUPEE PUMPING STATION SUMP AND OUTLET STRUCTURE
UPPER POINTE COUPEE LOOP AREA, LOUISIANA

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The site of the proposed Pointe Coupee pumping station, to be located in south-central Louisiana in the northernmost portion of Pointe Coupee Parish (Figure 1), is 2 miles* north of the town of Melville and about 32 miles northwest of Baton Rouge. The 128-square-mile drainage area is called the Upper Pointe Coupee loop and comprises primarily cropland, pastureland, and forestland. The area is enclosed by the Mississippi, Old, and Atchafalaya River levees and by the Morganza Floodway upper guide levee. Bayou Latenache and Johnson Bayou, the principal streams draining the area, collect rainfall runoff and convey the water to the existing Pointe Coupee gravity-flow drainage structure where it is discharged into the Morganza Floodway. The proposed Pointe Coupee pumping station would be located about 0.5 mile west of the gravity-flow drainage structure and would discharge flows into the Atchafalaya River.

2. Drainage of the Upper Pointe Coupee loop area was blocked by the construction of the upper guide levee of the Morganza Floodway which carries excess Mississippi River floodwaters to the Atchafalaya Basin Floodway. To provide for this drainage, the gravity-flow drainage structure was constructed. Extra storage was provided in the borrow pits that had been used to build the levee, and flood easements were purchased over some 20 square miles in the loop area located below el 35.0 NGVD.** However, flooding continued to affect

* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

the area due to an inadequate system of interior drainage and insufficient capacity of the drainage structure. High flood stages occurred in 1973 when the Morganza Floodway was operated for the first time. The high stage in the floodway necessitated the closing of the Pointe Coupee drainage structure. This action effectively prevented the floodwaters in the Morganza Floodway from entering the Pointe Coupee loop area; however, it also prevented any accumulated runoff within the area from draining. Eight inches of rain fell on the loop area while the floodway was operating. Serious flooding was prevented by placing into action 41 portable pumps with a total rated capacity of 1,400 cfs. This emergency measure was successful in keeping water levels in the area from exceeding el 34.0, 1 ft below the flood easement elevation. The proposed Pointe Coupee pumping station would provide for improved drainage in the loop area as well as provide flood-control capabilities during operation of the Morganza Floodway.

3. The original design of the pumping station is shown in Figures 2 and 3. With this design, the approach channel was symmetrical for 200 ft upstream from the pumping station. The channel had a base width of 150 ft with 1V-on-3.5H side slopes. The channel bank elevation was approximately 32.0. Quadrant wing walls with 100-ft radii were proposed to provide a streamlined transition from the approach channel to the pumping station.

4. The proposed pumping station will have three vertical 72-in. pumps operating with siphonic recovery. Design discharge for the station is 1,500 cfs, although the discharge per pump will range between 350 and 680 cfs, depending on the operating head and pump manufacturer. The pump suction bells will have 10.5-ft diameters and will be located 3.5 ft above the sump floor which is at el 10.0. The pumps will be started when the sump water surface is at el 21.0 and will be stopped when it is lowered to el 20.0. The maximum sump water surface will be el 26.0. The pumps will operate in individual sumps 26 ft wide and 98 ft long (measured from pump center line). Cooling water for the diesel engines that power the pumps will be provided through the raw water conduit located in the right (looking downstream) wall of the sump just

downstream of the sump entrance. The cooling system will have a capacity of 2,680 gpm and will discharge through a 15.5-in.-diam pipe located in the left wing wall, 5 ft from the sump wall, at el 10.0.

5. The three discharge pipes from the pumping station will carry flows over the Atchafalaya River levee into the outlet structure. The discharge pipes will transition to 10- by 10-ft box outlets. The invert of these outlets will be 5.5 ft above the floor of the basin. The concrete outlet structure will be 70 ft long and 46.5 ft wide. Tailwater elevations in the stilling basin will vary between el 3.1 and 46.0.

6. The outlet channel will be approximately 1,200 ft long d will carry pumped flows from the stilling basin into the Atchafa a River. The channel will have an invert elevation of -1.2, a bas idth of 80 ft, and 1V-on-4H side slopes. The bank elevation is appro mately 32.0. The channel invert and side slopes will be protect y riprap for the first 200 ft downstream from the stilling basin.

Purpose of Model Study

7. Pump performance can be adversely affected by unfavorable flow conditions at the pump intake. Air entrainment, vortex action, pressure fluctuations, and flow circulation in the pump sump can result in cavitation, vibration, and uneven stress on the pump. Some of the causes of these problems are low submergence of the pump impeller and unequal flow distribution entering the sump. Although some studies have been conducted to determine optimum sump design to eliminate or reduce these adverse effects, these studies have not yet produced sufficient information to develop general design criteria for pump sumps and approach channels.

8. The Pointe Coupee pumping station design requires an impeller submergence considerably lower than most general criteria recommend. The sump and approach channel model study was conducted to provide an assessment of the approach channel and sump performance for a range of anticipated operating conditions. The investigation was

also intended to develop practical modifications that would improve performance of the pump station.

9. The model study of the stilling basin and outlet channel was conducted in order to assess the ability of the basin to dissipate energy and ability of the riprap to protect the channel from scour. Necessary design modifications were to be developed during the model investigation.

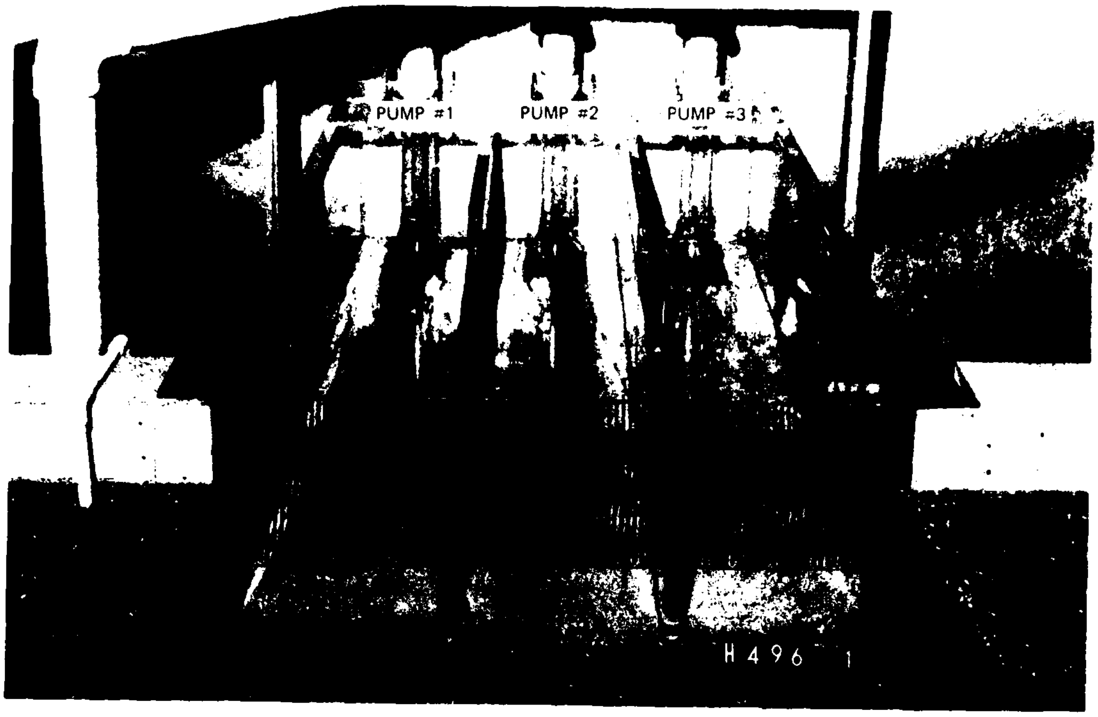
PART II: THE MODELS

Description

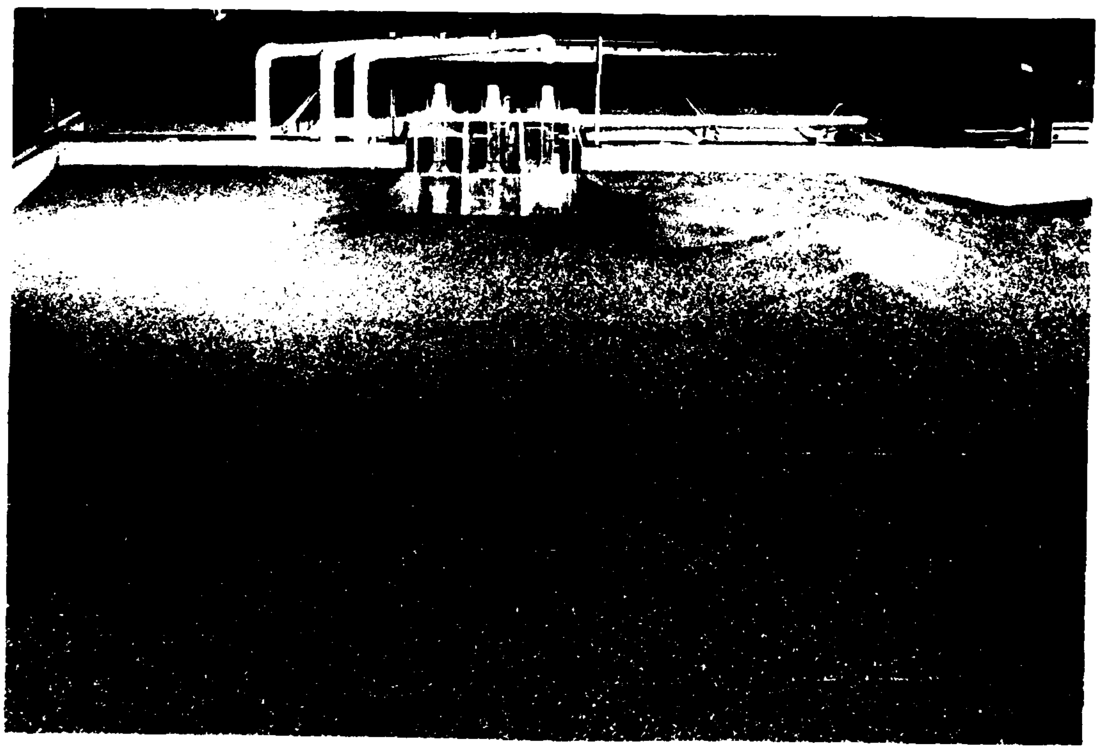
10. The models of the Pointe Coupee pumping station inlet and outlet structures were constructed to undistorted linear scale ratios of 1:18.75 and 1:19.2, respectively. The pump sump was fabricated of transparent plastic to allow observation of submerged flow conditions. Transparent tape scales were attached to the sidewall of the sump to indicate water-surface elevations. The quadrant wing walls that provided the transition from the approach channel to the sump were constructed of sheet metal. The approach channel was molded of pea gravel to sheet metal templates and extended 700 ft upstream from the sump. The outlet basin was also fabricated of transparent plastic, as were the discharge pipes that were simulated from the crown of the siphon into the basin. The outlet channel was molded of sand to sheet-metal templates, except where riprap was specified in the design. The models as originally designed are shown in Figures 2 and 3.

11. Flow through the models was recirculated by centrifugal pumps. Each pump column and discharge line had its own separate pump to permit simulation of various flow rates and operating conditions. In the sump model, flow was initially measured by turbine flowmeters and displayed electronically. In the course of the investigation, two of the turbine meters were removed and measurements were made using elbow meters that had been calibrated volumetrically in the model headbay. Flow discharging into the approach channel was distributed by causing it to pass over a weir and through a rock baffle. The cooling water system had a separate pump with flow measured by a rotameter. In the stilling basin model, flow was measured by paddle-wheel flowmeters and displayed electronically. Maximum velocities were maintained in the discharge pipes by keeping the air vents open at the top of the pipes. Water levels were adjusted in the models by adding or draining water.

12. Various instruments and methods were used to measure the

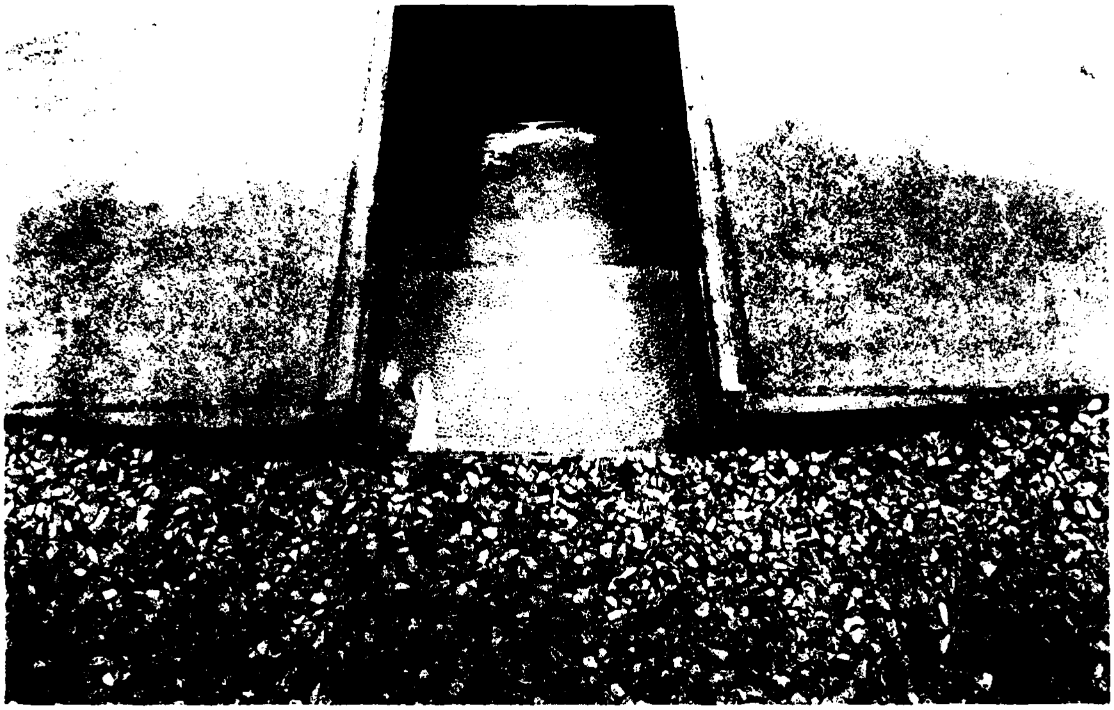


a. Pump sump

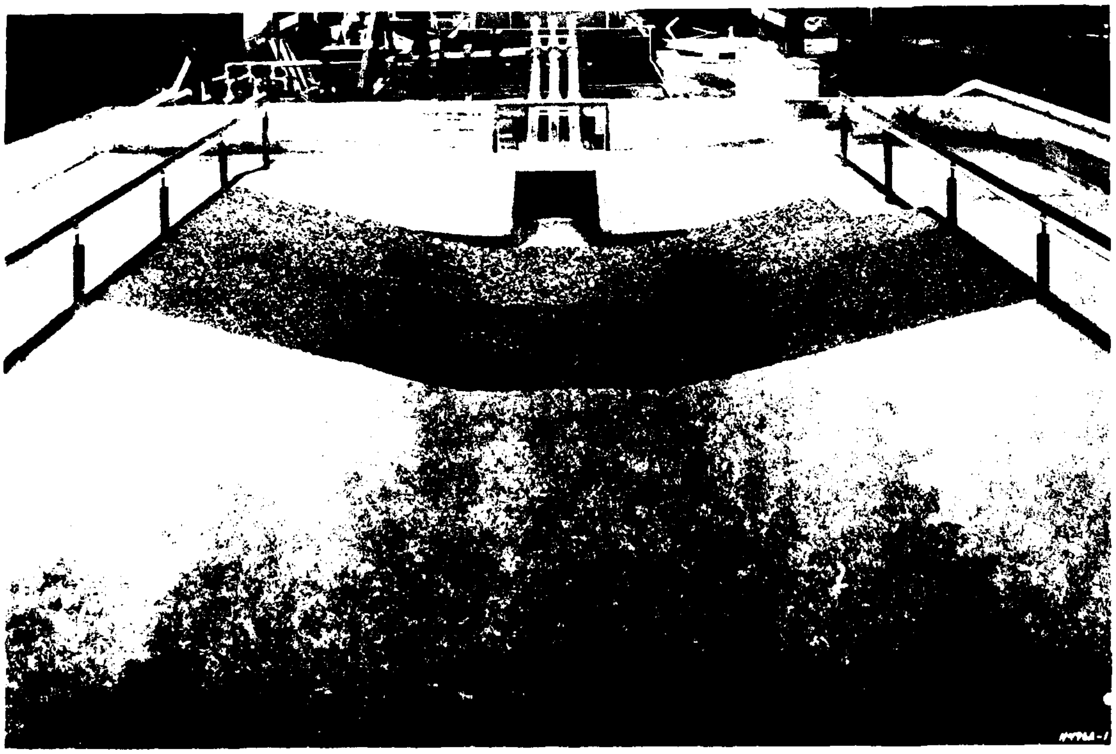


b. Approach channel

Figure 2. Type 1 (original) design of pump sump and approach channel, 1:18.75-scale model



a. Stilling basin



b. Outlet channel

Figure 3. Type 1 (original) design of stilling basin and outlet channel, 1:19.2-scale model

factors that affect pump and stilling basin performance. Electronic pressure transducers were placed beneath the pump bells to measure ins. ıntaneous pressure fluctuations; a time-history was provided on strip charts. Velocities were measured by a paddle-wheel velocity meter. Flow rotation into the pump column (swirl) was measured by counting revolutions of a freewheeling vortimeter with four zero-pitched blades mounted in the pump column. Confetti, dye, and partially submerged floats were used to observe and photograph flow patterns. Visual observations were used to determine vortex activity. Water-surface elevations were measured by point gages attached to a crossbar supported by level steel rails located on each side of both models. The primary means of monitoring flow conditions in the model, visual observation for vortex activity, a pressure transducer, and a vortimeter, are shown in Figure 4.

13. After the pump sump model was constructed, a design change was made to the thickness of the divider wall between the individual pump bays. The wall thickness was increased from 2.5 to 3.5 ft in order to allow for the placement of more reinforcing steel in the concrete walls. Engineers from the U. S. Army Engineer Districts, New Orleans and Memphis (LMN and LMM), the Lower Mississippi Valley Division, and the Office, Chief of Engineers, decided that this change would not affect flow into the sump; therefore no change was made to the model.

Interpretation of Model Results

14. The principle of dynamic similarity, which requires that the ratios of forces be the same in the model and prototype, is the basis for the design of models and the interpretation of results. Models involving a free surface are scaled to the prototype using the Froudian criteria because the flow phenomena are determined primarily by gravitational and inertial forces. Viscous forces can also influence the flow patterns and vortex formations; however, it has been found that when the Reynolds number exceeds 5×10^4 in the pump column, the

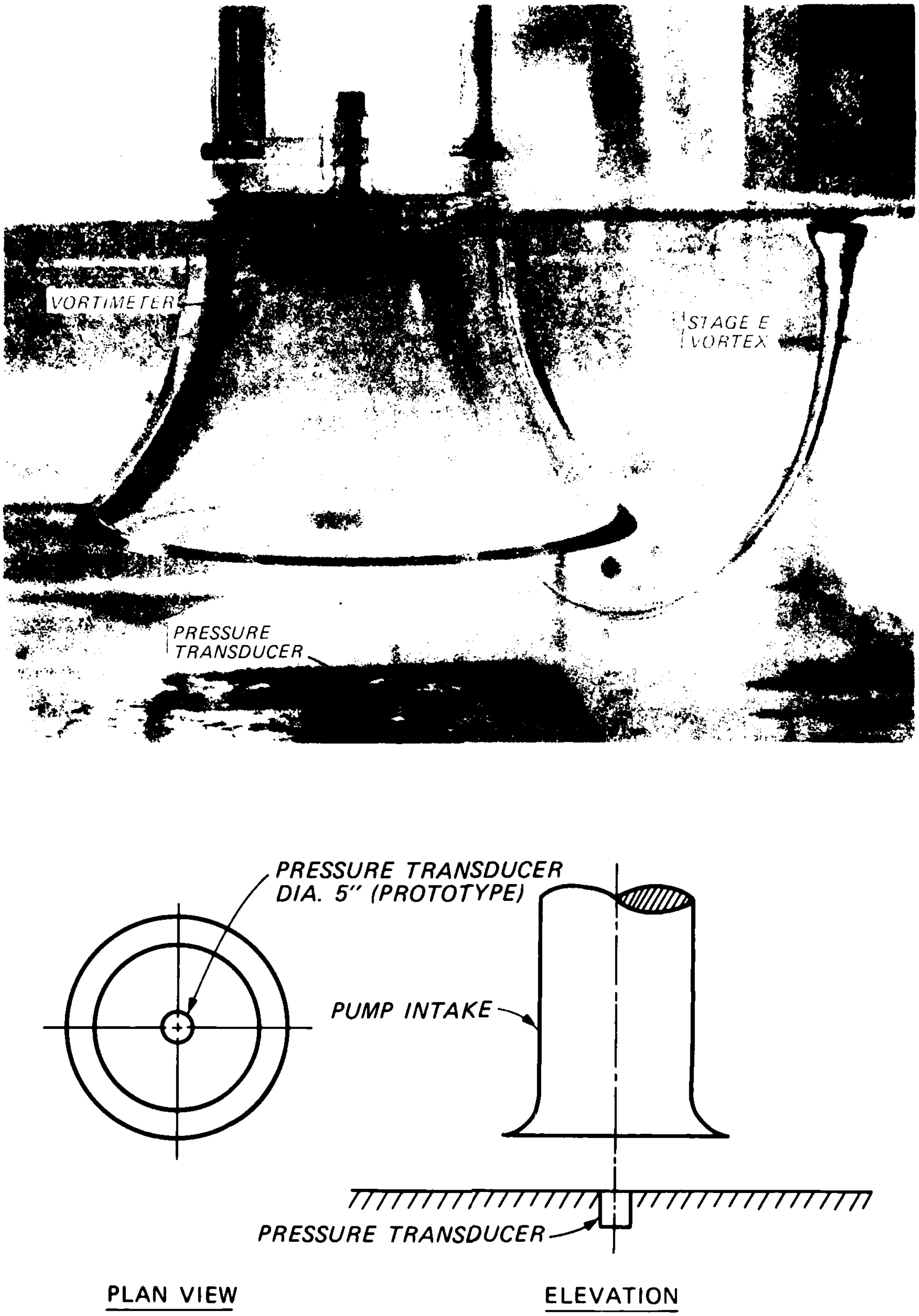


Figure 4. Flow condition monitors used in model investigation

viscous forces are negligible. The Reynolds number in the model pump column was 1.2×10^5. The general relations expressed in terms of the model scale or length ratio are as follows:

Dimension	Ratio	Scale Relation: Sump Model	Scale Relation: Outlet Model
Length	$L_r = L$	1:18.75	1:19.2
Velocity	$V_r = L^{1/2}$	1:4.330	1:4.382
Time	$T_r = L^{1/2}$	1:4.330	1:4.382
Discharge	$Q_r = L^{5/2}$	1:1,522	1:1,615
Pressure	$P_r = L$	1:18.75	1:19.2
Frequency	$F_r = L^{-1/2}$	1:0.2309	1:0.2282

Values for discharge, water-surface elevation, and pressure fluctuation can be transferred quantitatively from the model to the prototype by means of the scale relations above. Unless otherwise noted, all results reported herein will be in prototype units.

15. Adverse flow conditions into the pump intake induce pressure fluctuations, rotational flow, and vortex activity. There are currently insufficient prototype measurements to establish definite acceptable limits for these factors; however, general guidelines have been used at the U. S. Army Engineer Waterways Experiment Station (WES). For this model study, pressure fluctuations of less than 2 ft of water are considered acceptable. The severity of rotational flow or swirl into the pump column may be related to the angular velocity of the vortimeter or to the dimensionalized rotational flow indicator, R_i. The rotational flow indicator is the ratio of the tangential velocity at the tip of the vortimeter blade to the average axial velocity in the pump column and is equal to the tangent of the indicated swirl angle as used by many investigators. The rotational flow indicator is computed using the following formula:

$$R_i = \frac{U}{V_a}$$

where

$$U = \frac{\pi n d}{60}$$

n = angular velocity of vortimeter, rpm

d = pump column diameter, ft

V_a = average axial velocity in pump column, fps

The rotational flow indicator has the same value in the model and prototype and may be used to compare performance of sumps with different sizes and discharges. Sump performance was considered satisfactory in this study when the angular velocity of the vortimeter was less than 7 rpm and the rotational flow indicator was less than 0.09. Every attempt is made to eliminate vortex activity from the walls, floor, or water surface. The types of vortex formations and the stages of surface vortex development observed in this investigation are shown in Figure 5. Using these guidelines, acceptable pump sump design can be accomplished through the model investigation procedure.

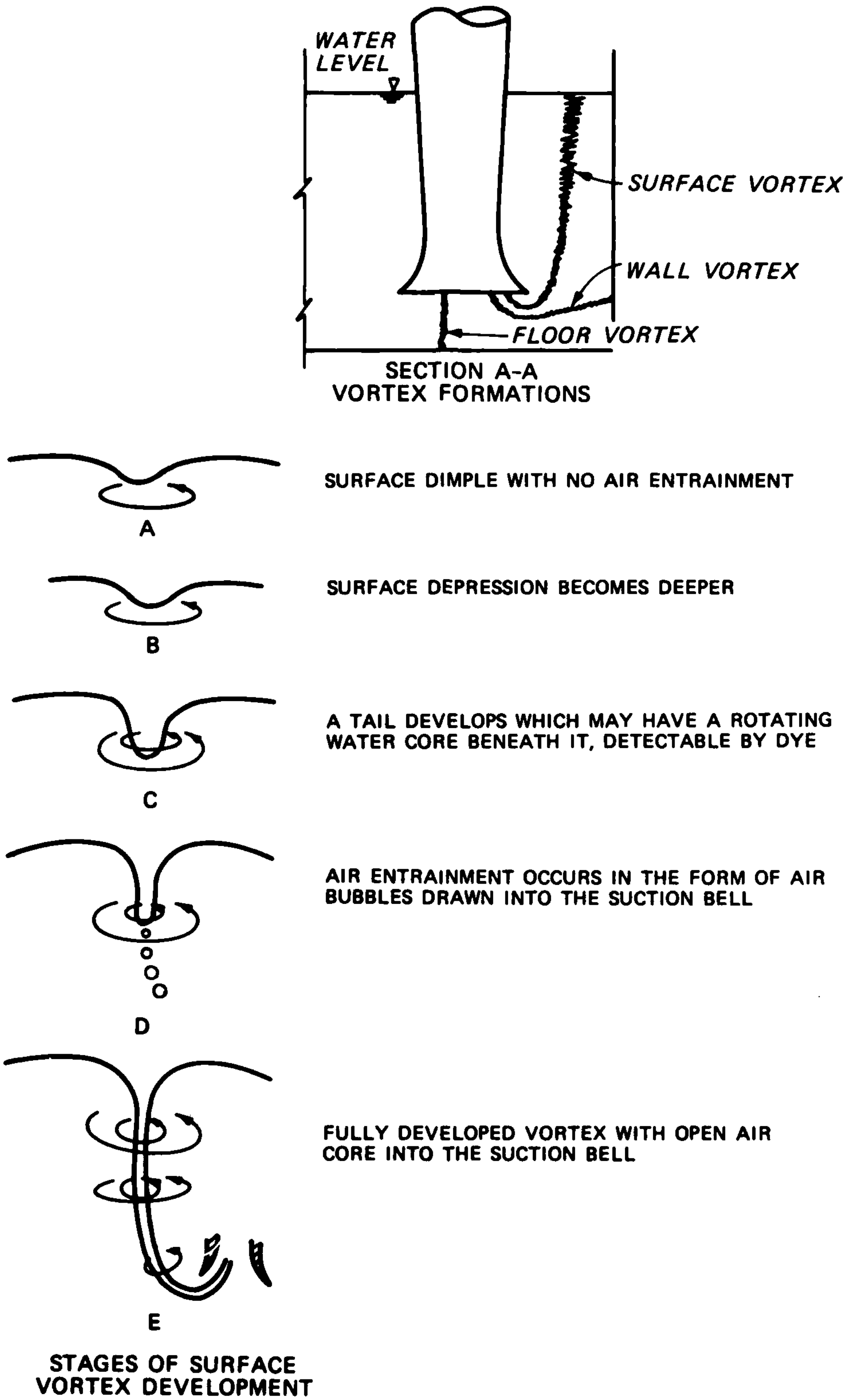


Figure 5. Vortex formations

PART III: TEST RESULTS

Method of Operation

16. The proposed pumping station consists of three pumps with three discharge pipes and outlets. The pumping station sump is designed to operate between water surface el 20.0 and 26.0. Tests were conducted at 1-ft intervals in this range with all three pumps operating. At el 20.0, various combinations of one and two pumps operating were also tested. The stilling basin was tested at tailwater el 46.0, which is the design flood stage; el 18.8, which is the average 50 percent chance stage; and at el 3.1, which is the minimum river stage. Tests at all three elevations were conducted with all three outlets discharging. At the lowest tailwater, tests were also conducted with different combinations of one and two outlets discharging. The maximum anticipated flow per pump of 613 cfs was used for initial testing; however, this value was increased to 680 cfs during the course of the testing program. The cooling water system was operated for all sump tests, except for one test where its effect on sump performance was found to be insignificant. Results of the sump model tests are shown in Tables 1-32, geometries of test sumps and approach channels are shown in Figure 6 and Plates 1-4, respectively, and pump numbers are shown in Figure 2.

Original Pump Sump Design

17. Testing of the type 1 (original) design sump and approach channel designs revealed that unfavorable hydraulic conditions would occur at all operating conditions (Table 1). Fully developed air entraining vortices occurred with a sump water surface at el 20.0 and surface dimples occurred with the water surface at el 26.0. Measurements of pressure fluctuation and swirl were satisfactory when all three pumps were operating; however, when one or two pumps were operating, conditions deteriorated. This deterioration was caused by the

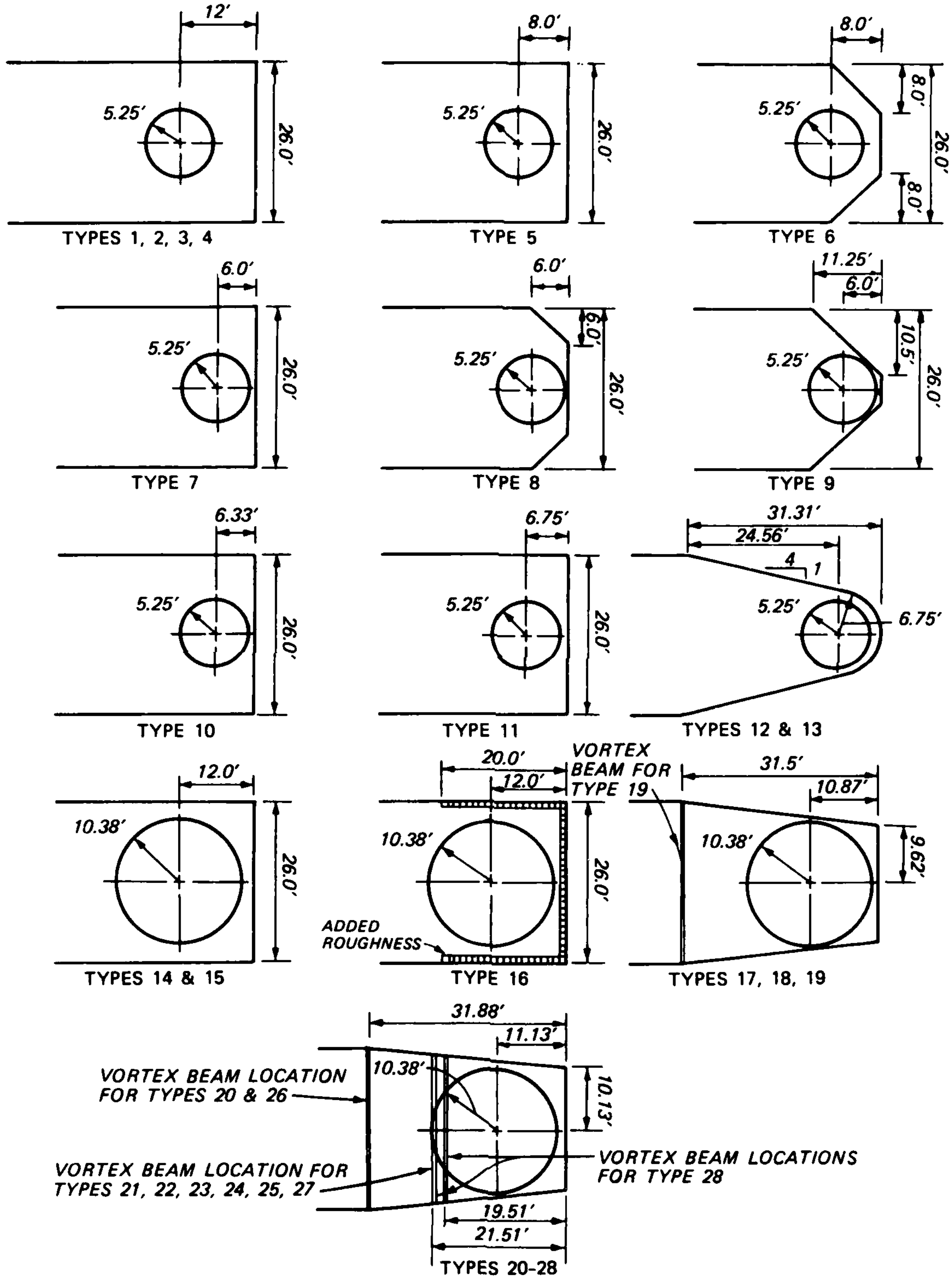


Figure 6. Geometries of test sumps

poor flow distribution entering the active sump when flow had to cross in front of an inactive sump. Conditions were most severe when pump 1 or pump 3 was operating alone.

Approach Channel Designs

18. The type 1 (original) design approach channel provided for a symmetrical channel for 200 ft upstream from the sump. The right bank of this channel was provided by a dike as shown in Figure 2 and Plate 1. Flow tended to concentrate on the left side of this approach channel and stagnation occurred at the head of the dike on the right bank. This caused a curvature of the flow as it approached the sump. This condition was least severe when all pumps were operating and most severe when only one pump was operating as shown in Photo 1. The type 1 design approach channel was used to test the type 1-9 design sumps.

19. After testing nine different sump designs (see Figure 6), attention was focused on approach channel improvements in an attempt to improve sump performance by eliminating the flow stagnation that occurred at the dike head. This was accomplished with the type 2 approach channel (Plate 2) by extending the dike upstream to connect with the existing bank located approximately 350 ft upstream. The type 2 design approach channel was compared with the type 1 design approach channel using the type 7 and 9 design sumps (Tables 4 and 5, and 7 and 8, respectively). Although the flow conditions in the approach channel were improved with the type 2 design approach channel, there was no significant improvement in sump performance. The type 2 design approach channel was also used in tests of the type 10 and 11 design sumps shown in Figure 6.

20. Further improvement was attempted with the type 3 design approach channel by making the right bank symmetrical to the left bank for 500 ft upstream from the sump as shown in Plate 3. Flow conditions for this design were not noticeably improved over the type 2 design approach channel. The conditions in the type 11 design sump were similar for the type 2 and 3 design approach channels (Tables 10

and 11). Flow conditions with all three pumps operating and with only pump 1 operating are shown in Photos 2a and 2b. These photographs show that when all three pumps were operating, the type 3 design approach channel provided a more uniform flow entering the sump. However, when only one pump was operating, flow entered the sump at an acute angle with all three approach channel designs, producing unfavorable conditions in the sump. It was apparent that as long as one or two pumps were not operating, the approach conditions could not be symmetrical; therefore, the correction of adverse entrance conditions must be solved with sump design modifications. It was also determined that hydraulic performance in the sump was essentially the same with the type 1, 2, and 3 design approach channels and that sump designs with different approach channels were comparable. The type 3 approach channel was used to test the type 11-27 design sumps shown in Figure 6.

21. The type 1 (original) design approach channel was preferred by LMN because less earthwork would be required. Therefore, after achieving an acceptable sump design, the original approach channel was reconstructed in the model and tested to check performance with the better sump designs. The type 1 design approach channel was deemed adequate for adoption as the final design and was used for subsequent tests of umbrella supports and the recommended and adopted (type 28) design sump (Figure 16).

22. During construction of the Pointe Coupee pumping station, a slope failure occurred along the right bank of the approach channel just upstream from the sump. Soil conditions were such that a modified (type 4) design approach channel was more practical to construct and was tested in the model. The type 4 design approach channel (Plate 4 and Photo 3) was tested with the type 28 design sump (Figure 16) and with the type 2 design umbrella supports (Figure 15), the final designs chosen for construction by LMN. Results with the type 1 (original) design and the revised (type 4) design approach channels are shown in Tables 30 and 31. Pressure fluctuations were about the same with both designs. There was a slight increase in swirl with the type 4 design approach channel, but the results were still below recommended values.

The vortex activity with the type 1 design approach channel consisted of intermittent surface dimples that occurred so infrequently (less than 10 percent of the time) that the sump was considered vortex-free. Surface dimples occurred more frequently with the type 4 design approach channel (10 to 30 percent of the time), but this level of vortex activity is considered to be acceptable. Flow patterns with the type 4 design approach channel are shown in Photo 4. The type 4 design approach channel performed within acceptable limits and was considered satisfactory.

Experimental Pump Sump Designs

23. After testing the type 1 (original) design sump, an attempt was made to reduce vortex action by raising and lowering the pump suction bell. The suction bell was originally located at el 13.5, 3.5 ft above the sump floor or 0.33D in terms of the suction bell diameter, D . The type 2, 3, and 4 design sumps had the suction bell located 0.20D, 0.45D, and 0.60D above the floor, respectively. The tests were run with all three pumps operating and with the type 2, 3, and 4 design sumps in bays 1, 2, and 3, respectively. The surface vortex stage observed in the type 2-4 design sumps is compared with that of the type 1 design sump and suction bell locations in the following tabulation:

	Surface Vortex Stage					
	Bay 1		Bay 2		Bay 3	
Elevation ft NGVD	Type 1 Design Sump 0.33D	Type 2 Design Sump 0.20D	Type 1 Design Sump 0.33D	Type 3 Design Sump 0.45D	Type 1 Design Sump 0.33D	Type 4 Design Sump 0.60D
32	0	A	0	A	0	B
29	B*	A	B	B	B	B
26	A	B	A	B	B	D
23	E	E	E	E	E	E
20	E	E	E	E	E	E

* See Figure 5, page 16, for explanation of A-E.

No improvement was noticed with the type 2 and 3 design sumps, and conditions deteriorated with the type 4 design sump. The suction bell was returned to its original elevation, 13.5, for further testing.

24. Vortex activity can often be reduced by moving the backwall of the sump closer to the suction bell. However, if the wall is too close to the suction bell adverse pressure fluctuations are set up on the sump floor beneath the suction bell, and submerged vortices may develop off the backwall. The distance from the suction bell to the backwall in terms of suction bell diameter was 0.64D for the original design sump. Backwalls located 0.26D (type 5 design sump, Table 2) 0.17D (type 11 design sump, Table 10), 0.10D (type 10 design sump, Table 9), and 0.07D (type 7 design sump, Table 5) were tested with a standard type suction bell and rectangular sumps.* The vortex activity decreased as the backwall was moved closer to the suction bell, with the least activity occurring with the type 7 design sump; however, air-entraining surface vortices were still present at the lowest sump water-surface elevation. The maximum pressure fluctuations occurred when a single pump was operating and are shown in Figure 7 for the five designs tested. Pressure fluctuations tended to improve as the backwall distance was decreased and then deteriorated with the type 7 design sump when the backwall became too close. Swirl was not significantly affected by the location of the backwall. It was apparent that moving the backwall closer improved hydraulic conditions somewhat but not sufficiently.

25. In order to reduce circulation in the corner of the sump behind the pump, fillets are often employed. In the type 6 design sump, 45-deg fillets were installed in the type 5 design sump. The fillets connected points along the backwalls and sidewalls located 8 ft from the corners. This design resulted in a slight improvement in pressure

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* The type 1 and 5 design sumps were tested with the type 1 design approach channel while the others were tested with the type 2 design approach channel so results are not directly comparable. Hovever, it was determined that the different approach channel designs had an insignificant effect on sump performance.

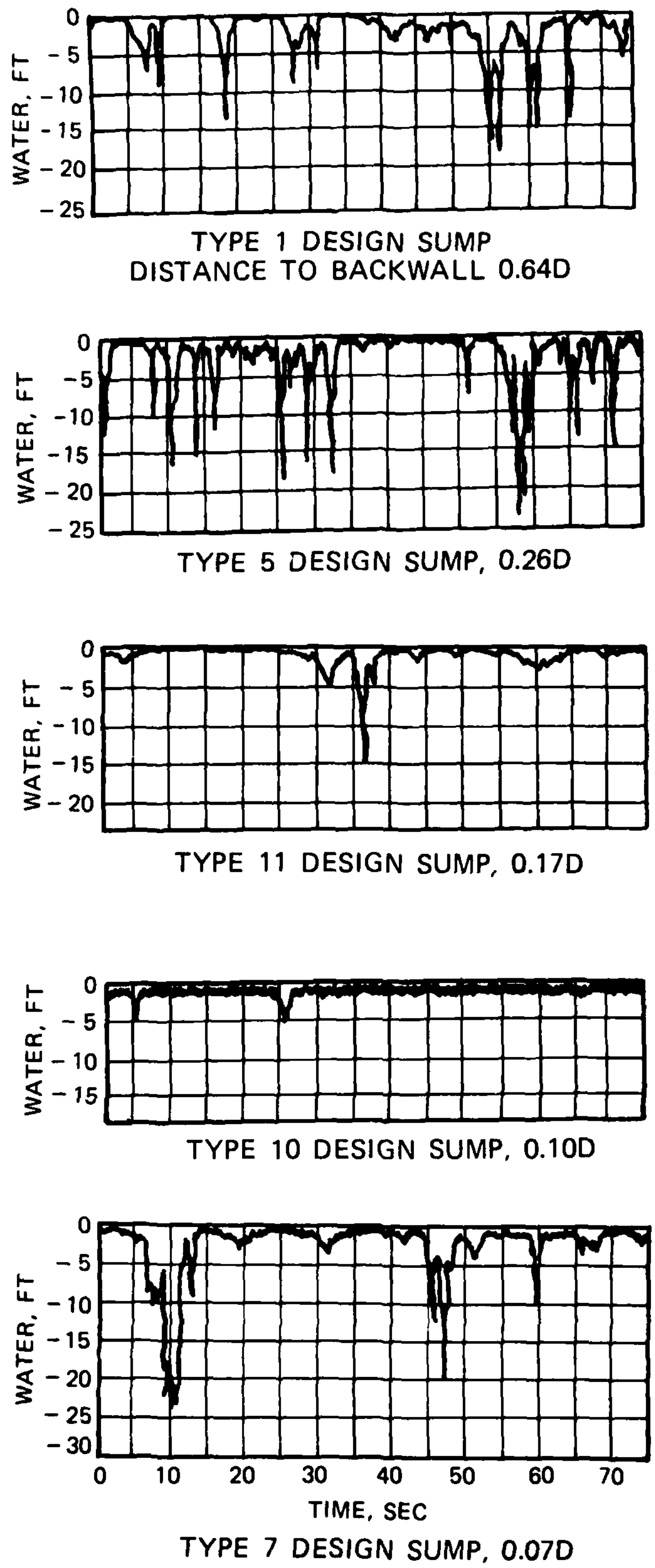

Figure 7. Pressure fluctuations with one pump operating at water surface el 20.0 with 613-cfs discharge

fluctuations, but no significant improvements in swirl or vortex activity (Table 3). In the type 8 design sump, 45-deg fillets connecting points along the backwalls and sidewalls located 6 ft from the corners were installed in the type 7 design sump. Again, a slight improvement in pressure fluctuations was recorded, but no significant improvement in swirl or vortex activity was observed (Table 6). From these tests it was concluded that fillets provided only a slight improvement in hydraulic conditions.

26. Converging sidewalls reduce circulation behind the pump column by directing flow into the suction bell and by occupying stagnant areas in the corners of the pump sump. The converging sidewalls tested in the type 9 design sump extended 11.25 ft from the backwall such that the minimum distance between the wall and the bell was 0.07D. With this design, the severe air-entraining surface vortices were eliminated; however, surface dimples and stage B vortices were occasionally observed (Table 7). In addition, submerged sidewall vortices appeared where the suction bell was closest to the sidewall. This type of vortex occurs when the pressure along the sidewall is reduced sufficiently to cause air to be removed from solution in the water. The converging sidewalls significantly reduced swirl. The most significant improvement was noted when less than three pumps were operating, indicating that the flow was being directed more evenly into the suction bell, even when approach conditions were unfavorable. Although some improvement was noted when less than three pumps were operating, pressure fluctuations were still excessive. It was apparent that converging sidewalls would significantly improve the hydraulic conditions, but the walls needed to be farther away from the suction bell.

27. Converging sidewalls were combined with a rounded backwall located 0.14D (1.5 ft) from the suction bell in the type 12 design sump (Table 13). With this design, pressure fluctuations were greater than those with the type 9 design sump. Surface dimples occurred with the water surface at el 26.0 and air-entraining vortices occurred with the water surface at el 20.0. A submerged vortex was observed with the water surface at el 25.0, but was less severe than that with the

type 9 design sump. Swirl was reduced, apparently due to the greater length of the converging sidewalls. It was concluded that the rounded backwall increased surface vortex activity.

28. The effective suction bell diameter can be increased by streamlining the lip of the suction bell. This was done in the type 13 design sump, Figures 6 and 8, which retained the type 12 design sump dimensions. This slight modification resulted in a significant drop in pressure fluctuations, but no significant improvement in swirl or surface vortex action occurred. Submerged floor vortices were observed at the higher sump water-surface elevations (Table 14).

29. The diameter of the suction bell can be significantly increased by adding an umbrella. Umbrellas with a 20.75-ft diameter were used in the type 14 design sump shown in Figure 9, which had the same sump dimensions as the type 1 (original) design sump. The umbrellas reduced the distance to the backwalls from 0.64D to 0.15D.* The severe air-entraining vortices that occurred with the type 1 design sump were reduced to surface dimples with the umbrellas. Pressure fluctuations and swirl were also reduced, but were still excessive when less than three pumps were operating (Table 15). The addition of the umbrellas was the single most effective method of improving hydraulic conditions.

30. The wing walls located at the sump entrance are intended to provide a smooth transition from the approach channel into the sump. The original quadrant wing walls had 100-ft radii (Plate 1) and were used in most of the model sump tests. However, two other wing wall configurations were tested. The type 15 design sump had parallel wing walls extending 200 ft upstream from the intake structure while the sump dimensions were the same as those for the type 14 design sump. The type 18 design sump had 45-deg wing walls (Figure 10) and had the same sump dimensions as the type 17 design sump (Figure 6). The wing wall layouts that were tested with the type 3 design approach channel (Plate 3) are shown in Figure 10. The parallel wing walls resulted in

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* D continues to refer to the suction bell diameter (10.5 ft) rather than the diameter of the umbrella.

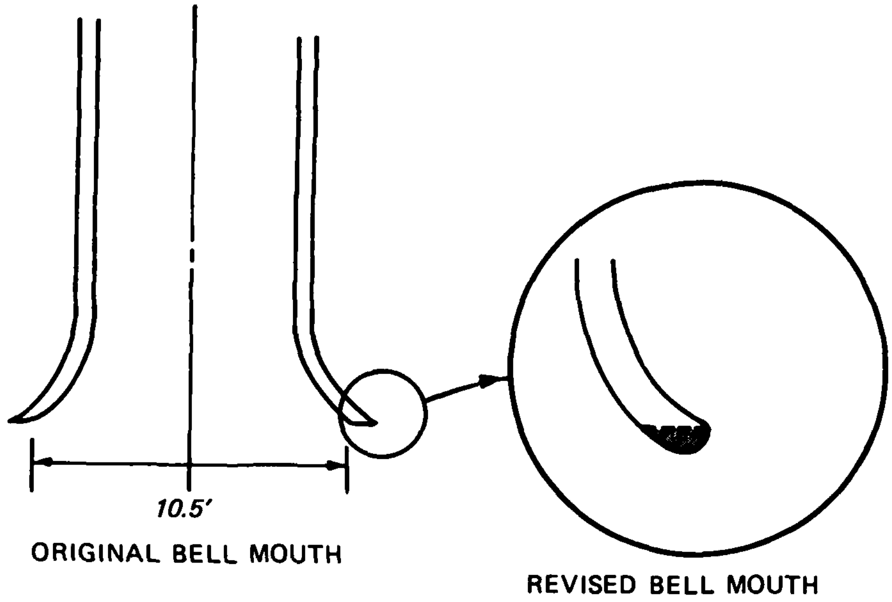


Figure 8. Bell-mouthed revision used in type 13 design sump

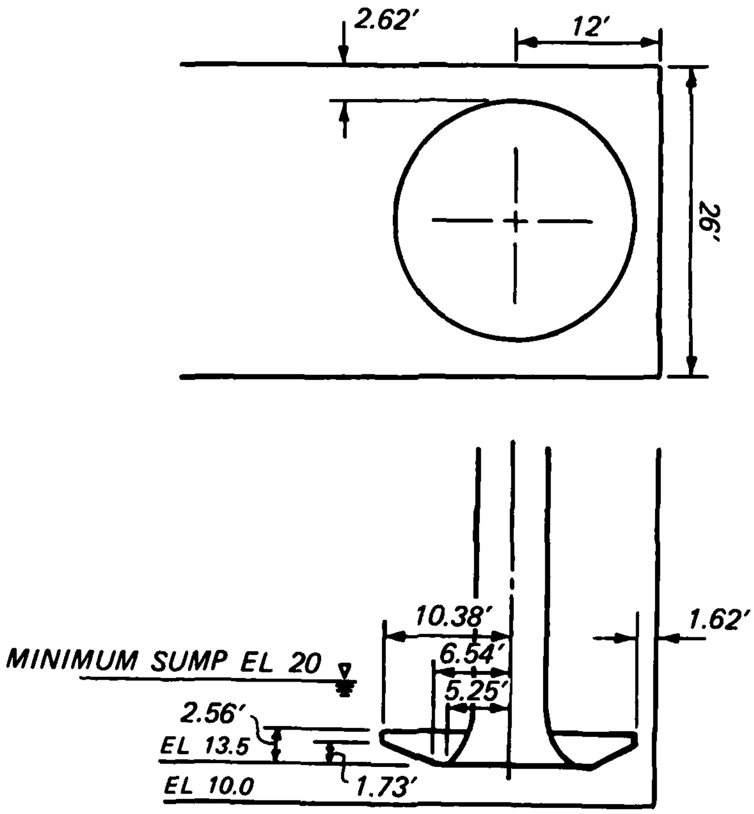
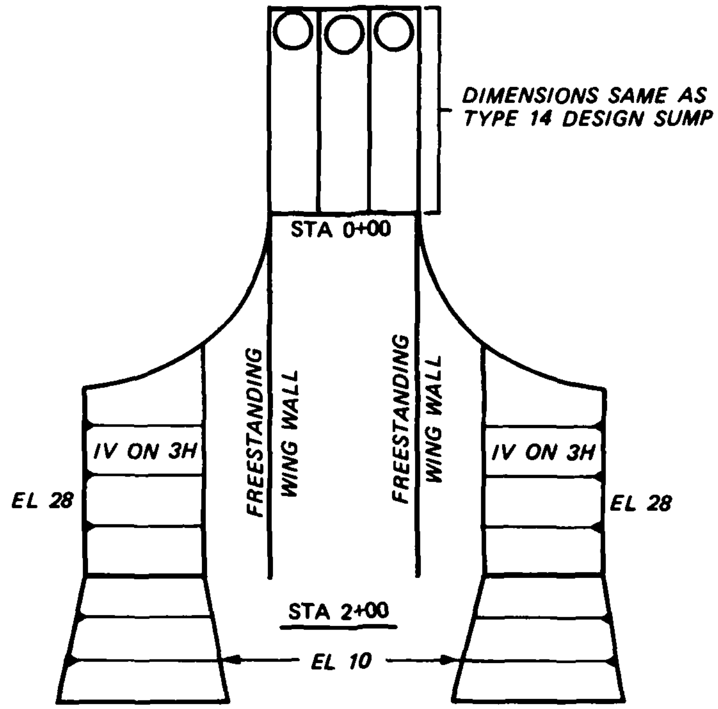
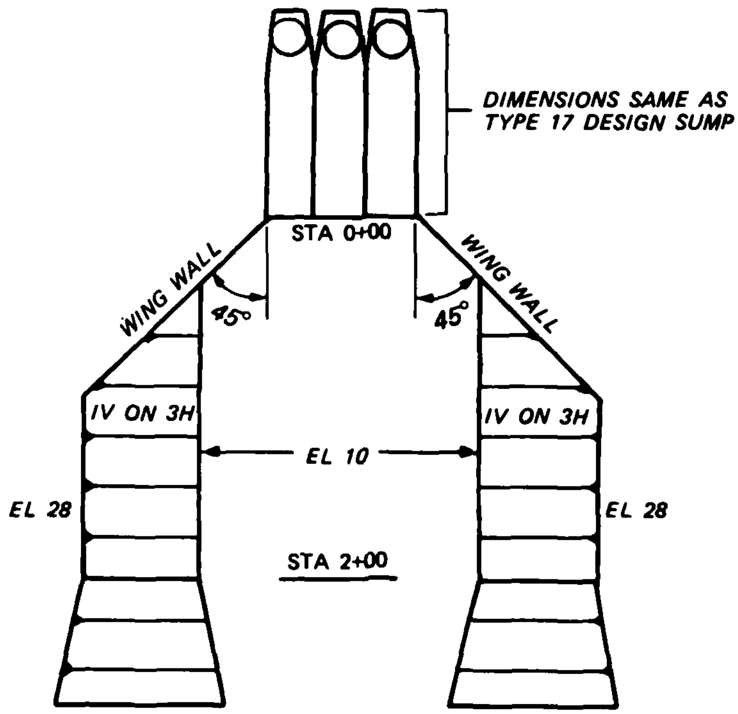


Figure 9. Type 14 design sump



TYPE 15 DESIGN SUMP



TYPE 18 DESIGN SUMP

Figure 10. Wing wall designs

no improvement in flow conditions (compare Tables 15 and 16); the 45-deg wing walls caused a slight increase in vortex activity (compare Tables 18 and 19). Tests indicated that the original wing walls provide better flow transition from the approach channel into the sump than the 45-deg wing walls and are just as good as the less practical 200-ft-long freestanding wing walls. The quadrant wing walls were used in subsequent testing.

31. Flow within the sump can be redistributed in a more uniform fashion by increasing the roughness of the sump walls. This was done in the type 16 design sump (Figure 11) by adding grids or waffle boards to the walls of the type 14 design sump. The grids, approximately

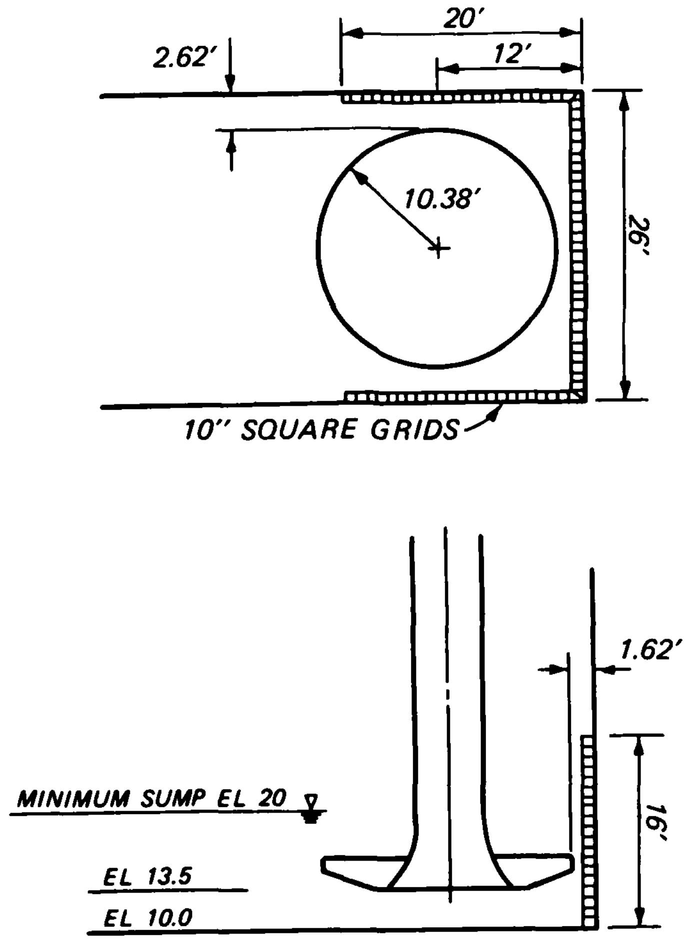


Figure 11. Type 16 design sump

10 in. square and 10 in. thick, were placed on the backwall and along the sidewalls for a length of 20 ft and to a height above the sump floor of 16 ft. With the type 16 design sump, only surface dimples were observed; and pressure fluctuations and swirl were within acceptable limits for all operating conditions (Table 17). The New Orleans District, however, felt that the grids would be difficult to construct and maintain; thus an alternate solution was required.

32. Testing with the type 9 and 12 design sumps had demonstrated the effectiveness of converging sidewalls and a backwall closer to the suction bell in reducing vortex activity, pressure fluctuations, and swirl. In the type 17 design sump (Figure 6), converging sidewalls extended 31.5 ft from the backwall, such that the minimum distance between the umbrella and the sidewalls or backwall was 6 in. (0.05D). With this design the pressure fluctuations and swirl were reduced to an acceptable range for all conditions tested; however, some surface vortex activity was still present (Table 18).

33. Vortex suppressor beams were added to the type 17 design sump to reduce the vortex activity. In the type 19 design sump, the beam was located one-half the umbrella diameter upstream from the lip and was 4 ft high extending between el 18.5 and el 22.5 (Figures 6 and 12). Vortex activity was eliminated when all three pumps were operating; however, surface dimples occurred when only one or two pumps were operating, and pressure fluctuations were intermittently excessive (Table 20).

34. The intermittently excessive pressure fluctuations that characterized the type 19 design sump were eliminated in the type 20 design sump (Figures 6 and 12) by increasing the minimum clearance between the umbrellas and the sump walls to 9 in. (0.07D) (Table 21). In addition, the height of the vortex suppressor beam was reduced to 1 ft, extending between el 19.5 and 20.5. Vortex activity increased with the type 20 design sump.

35. Several sump tests were conducted to determine a vortex beam configuration that would satisfactorily reduce surface vortices without increasing pressure fluctuations (Tables 22-26). Vortex

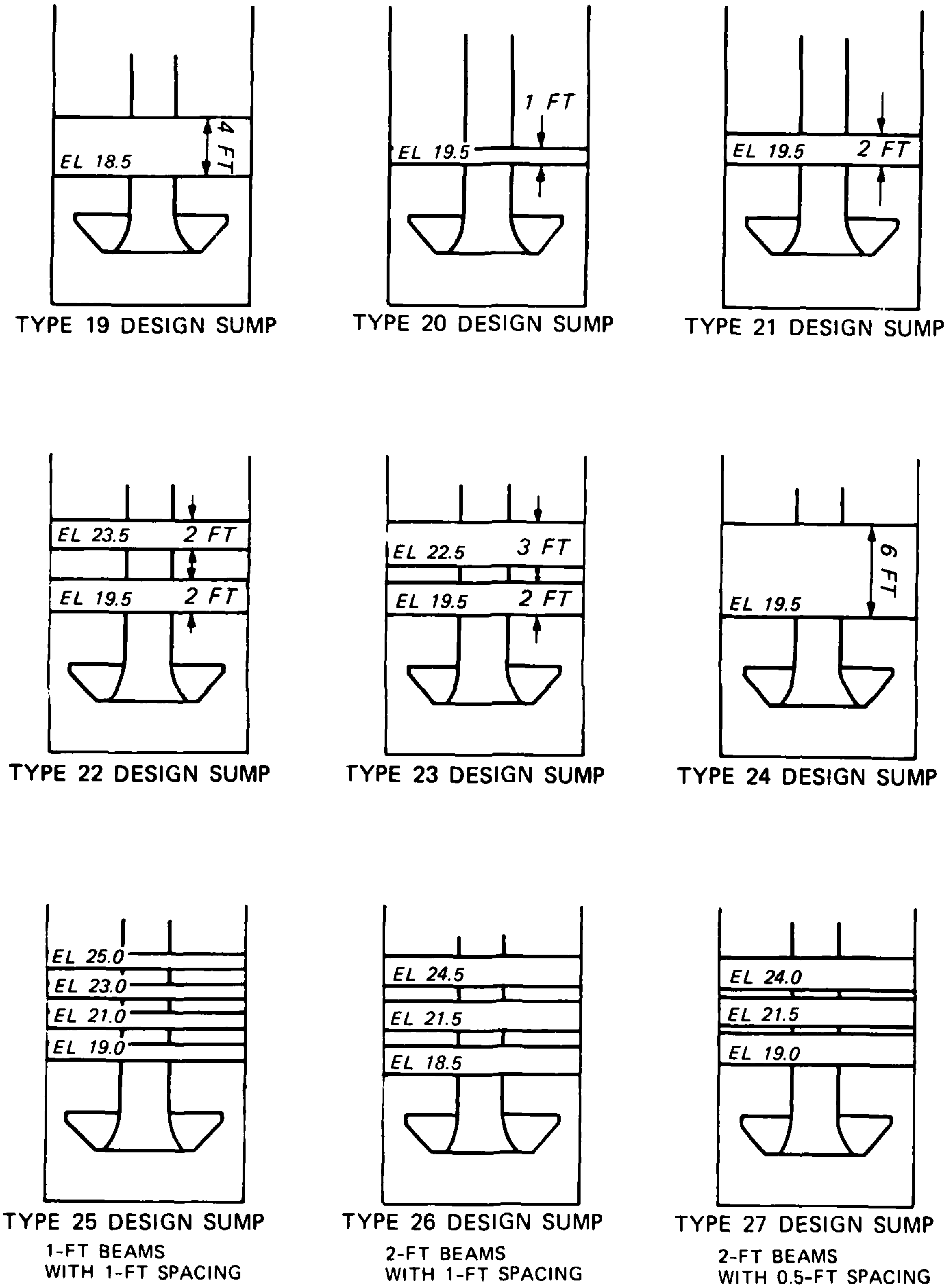


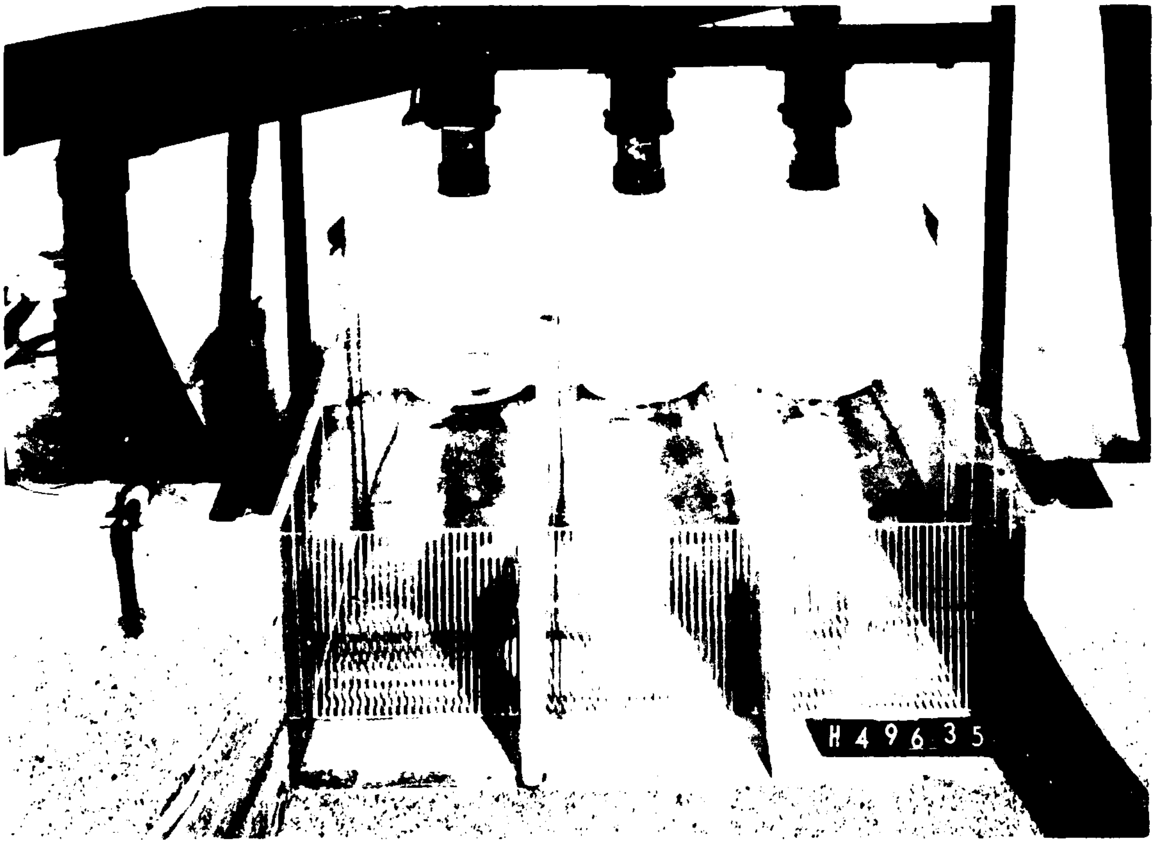
Figure 12. Vortex suppressor beams

suppressor beams tested are shown in Figures 6 and 12. Model tests indicated that a horizontal beam of any height located directly over the front lip of the umbrella and extending 1 ft into the water would eliminate vortex activity. However, as the water level increased and the depth of flow over the top of the beam reached 1 to 2 ft, vortices reoccurred. A solid horizontal beam extending through the entire range of operating sump water-surface elevations caused intermittently excessive pressure fluctuations. After testing several combinations of vortex suppressor beam sizes and spacings, it was determined that four 1-ft beams spaced 1 ft apart extending from el 19.0 to el 26.0 and located directly over the umbrella lip (type 25 design sump) were the most effective in reducing vortex activity and limiting pressure fluctuations.

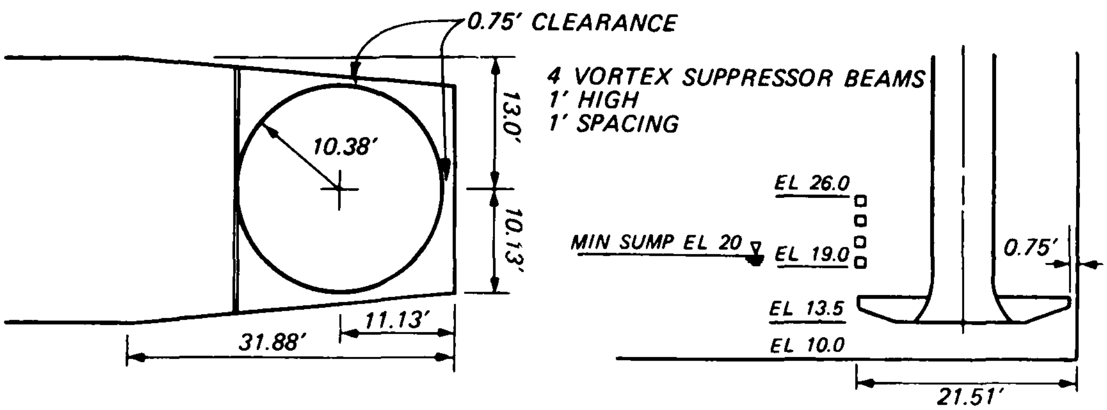
Recommended Pump Sump Designs

36. The type 25 design sump (Figure 13) was recommended based on the hydraulic model test results. This design provided a 20.75-ft-diam umbrella on the suction bell. The sidewalls converged on an angle of 5.14 deg from a point upstream from the umbrella lip equal to one-half the umbrella's diameter, such that the minimum distance between the umbrella and the sidewalls and backwalls was 9 in. Four vortex suppressor beams were placed over the upstream lip of the umbrella. These beams were 1 ft high, with 1-ft spacings, and extended from el 19.0 to el 26.0. Pressure fluctuations for the original and recommended designs at a sump water-surface elevation of 20.0 are shown in Figure 14. Velocities in the sump, 31.14 ft upstream from the pump column center line, are shown in Plates 5 and 6. With this sump design, pressure fluctuations were 2 ft of water or less, the rotational flow indicators were less than 0.09, and vortex activity consisted of surface dimples that occurred less than 10 percent of the time.

37. Originally, the umbrellas were to be supported by the suction bell. Two alternative umbrella support designs (Figure 15) were tested in which the umbrella was not supported by the suction bell.



a. Model sump



b. Plan and profile

Figure 13. Recommended type 25 design sump

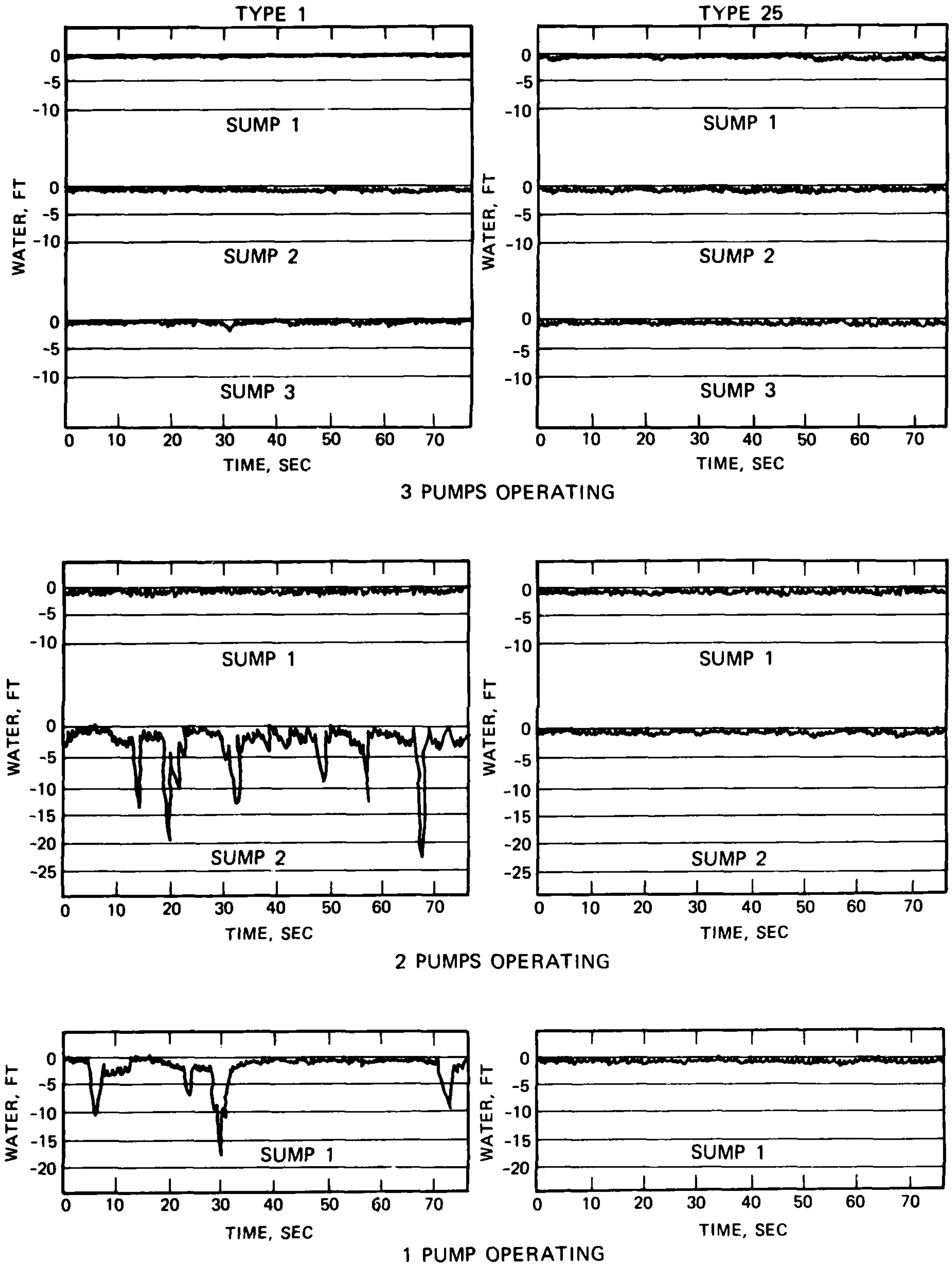


Figure 14. Pressure fluctuations--type 1 and 25 design sumps, water surface el 20.0

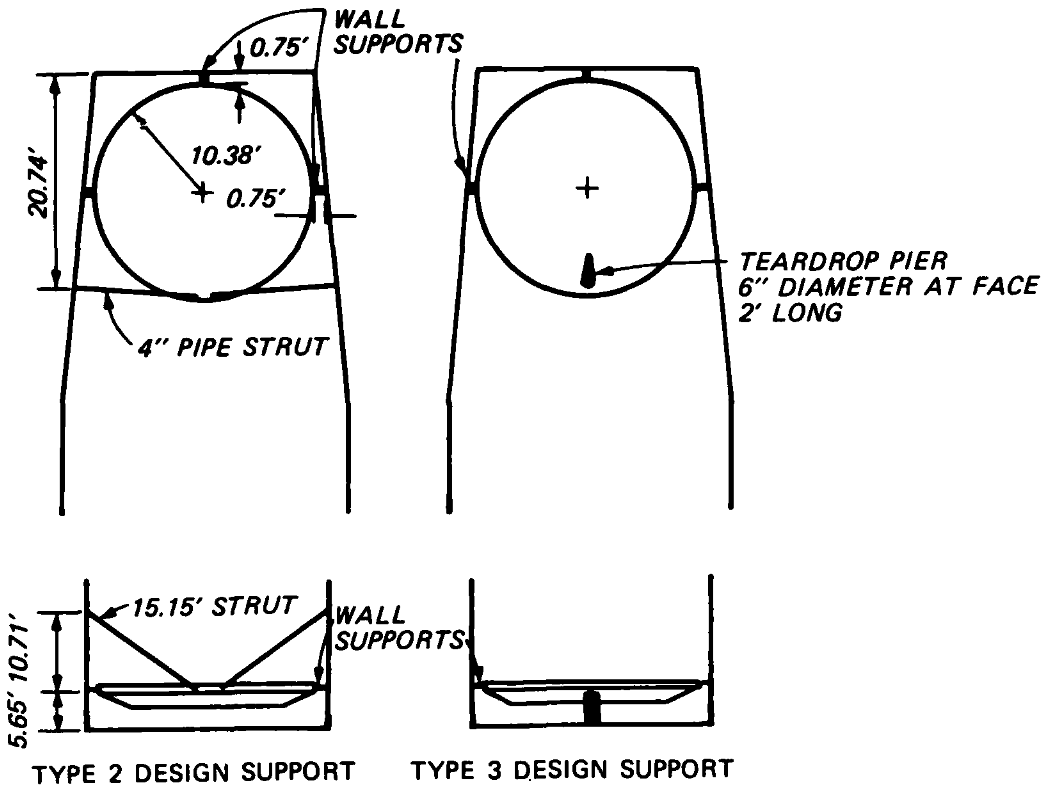


Figure 15. Umbrella supports

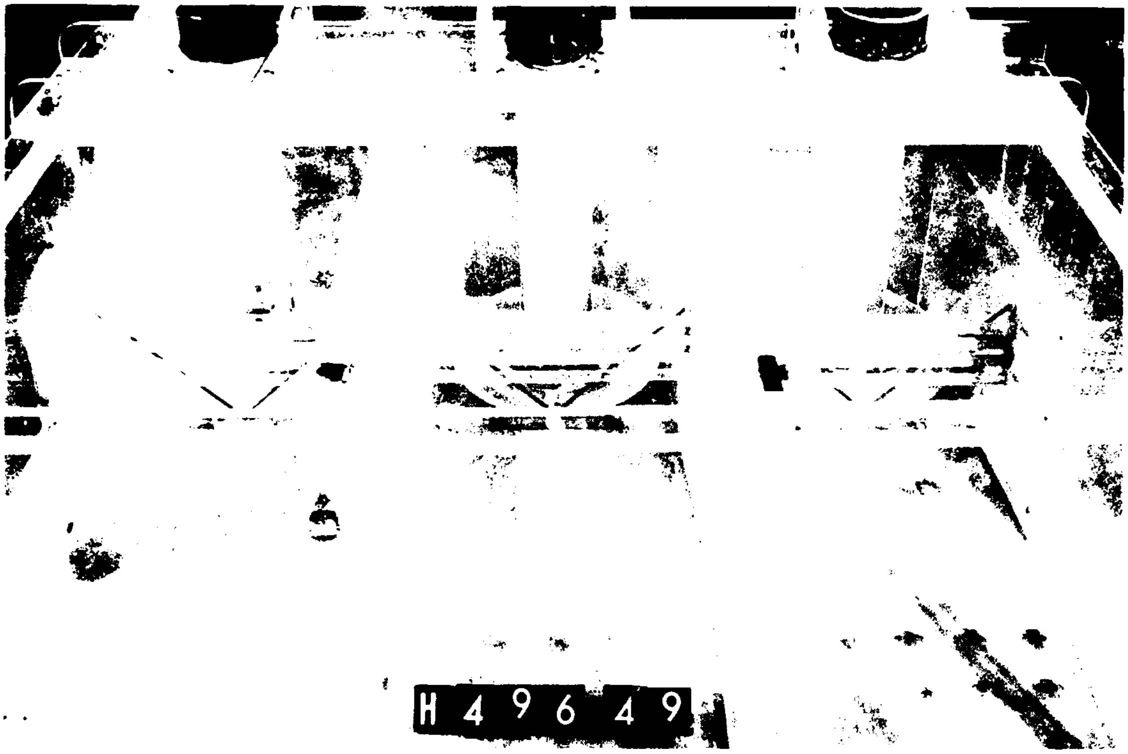
Both of these designs called for hollow J-bulb seals between the suction bell and umbrella, with supports on the backwalls and sidewalls. In addition to the wall supports, the type 2 design umbrella supports consisted of two pipe struts connecting the front lip of the umbrella to the sidewalls. With the type 3 design umbrella supports, the front lip of the umbrella was supported by a teardrop pier located beneath the umbrella. Initial test results indicated that both alternatives would function adequately (Tables 28 and 29).

38. In the course of testing the type 3 design umbrella support, it was determined that a slight misalignment of the pier would create excessive flow rotation into the pump column. This adverse condition could also occur in the prototype if debris accumulated on the pier. Due to the sensitivity of the pier's location, the type 2 design support with the pipe struts was recommended for the prototype.

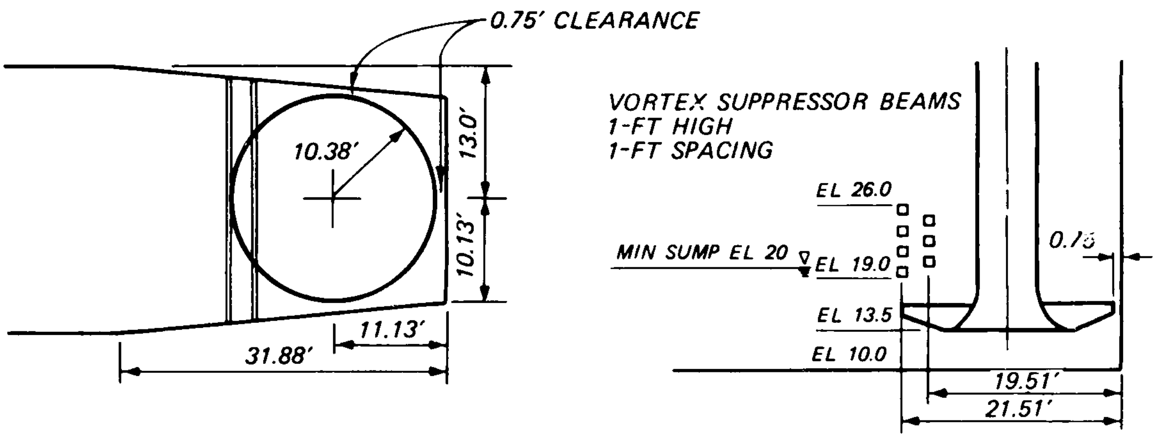
39. Subsequent to the completion of testing on the Pointe

Coupee pumping station model in August 1980, tests on various configurations of vortex suppressor beams were conducted in the generalized pump station research model at WES. Vortex suppressor beams similar to those recommended for the Pointe Coupee pumping station were tested in the generalized model and found to be unsuccessful in eliminating surface vortices when the sump water-surface elevation was at a level between the horizontal beams. This problem was eliminated by adding a second row of staggered beams downstream from the first row in the generalized facility. The second row of staggered beams allows for continuous submergence of a vortex suppressor at all sump operating levels without the flow blockage and head losses created by a single solid beam. This design with the type 2 design umbrella supports was tested in the Pointe Coupee pumping station model (Figure 16, Table 30). The infrequent surface dimples present in the type 25 design sump still occurred with the type 28 design sump, but less frequently. Velocities in the type 28 design sump and type 4 design approach channel, 31.14 ft upstream from the pump center line, are shown in Plates 7 and 8. This design produces a slight improvement in hydraulic conditions and was recommended and adopted for prototype construction.

40. The type 25 design sump was tested at sump water surfaces above and below the design operating elevations (Table 32). At high water-surface elevations the sump was tested with all three pumps operating. When the water level exceeded el 27.0 the vortex suppressor beams ceased to provide surface turbulence and vortex activity increased significantly. Stage C vortices developed as bubble accumulation made the vortex core visible. The vortices occurred more frequently at the higher water-surface levels. Pressure fluctuations and swirl were within acceptable ranges at higher water levels. Low water levels were tested with only pump 3 operating. As the water level dropped below el 20.0, conditions began to deteriorate. At el 19.0 and 18.0, stage A vortices were observed; but swirl and pressure fluctuations were within acceptable limits. At el 17.0, conditions were severely adverse, with the development of continuous floor vortices and stage B surface vortices. The rotational flow indicator increased



a. Model sump



b. Plan and profile

Figure 16. Recommended and adopted type 28 design sump

to 0.44 and the pressure fluctuations were 6 ft of water. At el 16.0, the strength of the floor vortex increased and mass circulation of flow occurred around the pump bell. The vortimeter was rotating too fast to count revolutions and pressure fluctuations were 16 ft of water. Although operating conditions were not ideal outside the design operating water-surface elevations, hydraulic conditions were not adverse between el 18.0 and 32.0; however, below el 18.0 severely adverse conditions developed.

Original Stilling Basin Design

41. The 1:19.2-scale model of the type 1 (original) design stilling basin is shown in Figure 3; stilling basin and outlet channel dimensions are shown in Figure 17. The pump station discharge pipes transition to 10-ft square conduits as they enter the stilling basin. The invert of the square outlets was at el 3.0. The stilling basin floor, at el -2.5, was 70 ft long and 46.5 ft wide with a 1.3-ft-high and 1V-on-1H sloping end sill. The invert of the outlet channel, at el -1.2, was 80 ft wide. The model was tested at tailwater elevations of 46.0, 18.8, and 3.1. The basin performed satisfactorily at the higher tailwater elevations; however, at the lowest tailwater elevation the basin was unsuccessful in dissipating energy. A large rooster tail was created as flow was deflected upward by the end sill, and the plunging flow caused the riprap downstream to fail. Flow conditions at each tailwater tested are shown in Photos 5-7. It was apparent that significant modifications would be necessary to provide adequate energy dissipation. The experimental stilling basins tested are shown in Figure 18.

Experimental Stilling Basin Designs

42. Stilling basin performance was significantly improved by adding a single row of baffles to the basin. In the type 2 design stilling basin the baffles, located 25 ft from the backwall, were 2 ft

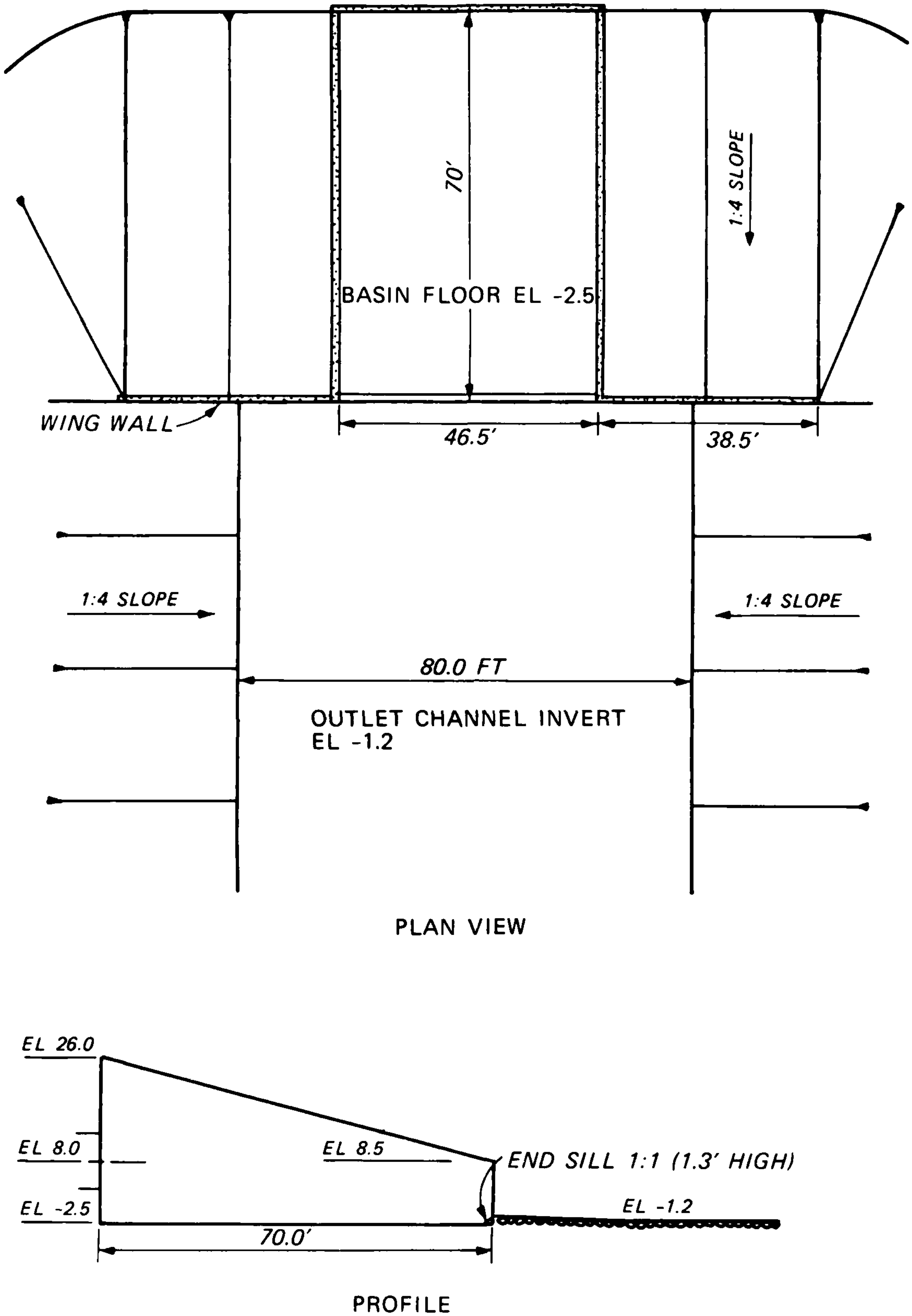


Figure 17. Type 1 design stilling basin

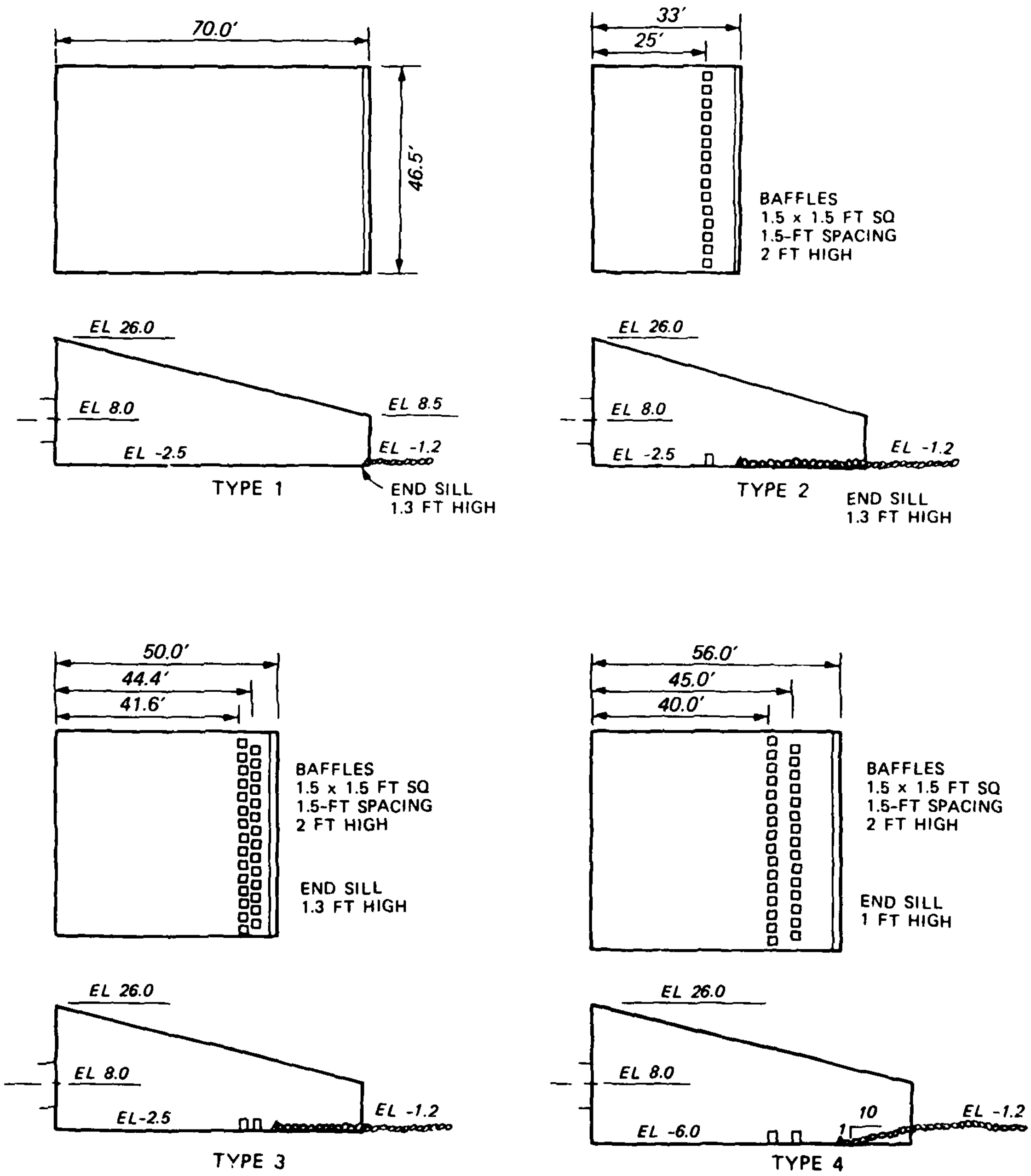


Figure 18. Experimental stilling basin designs (Continued)

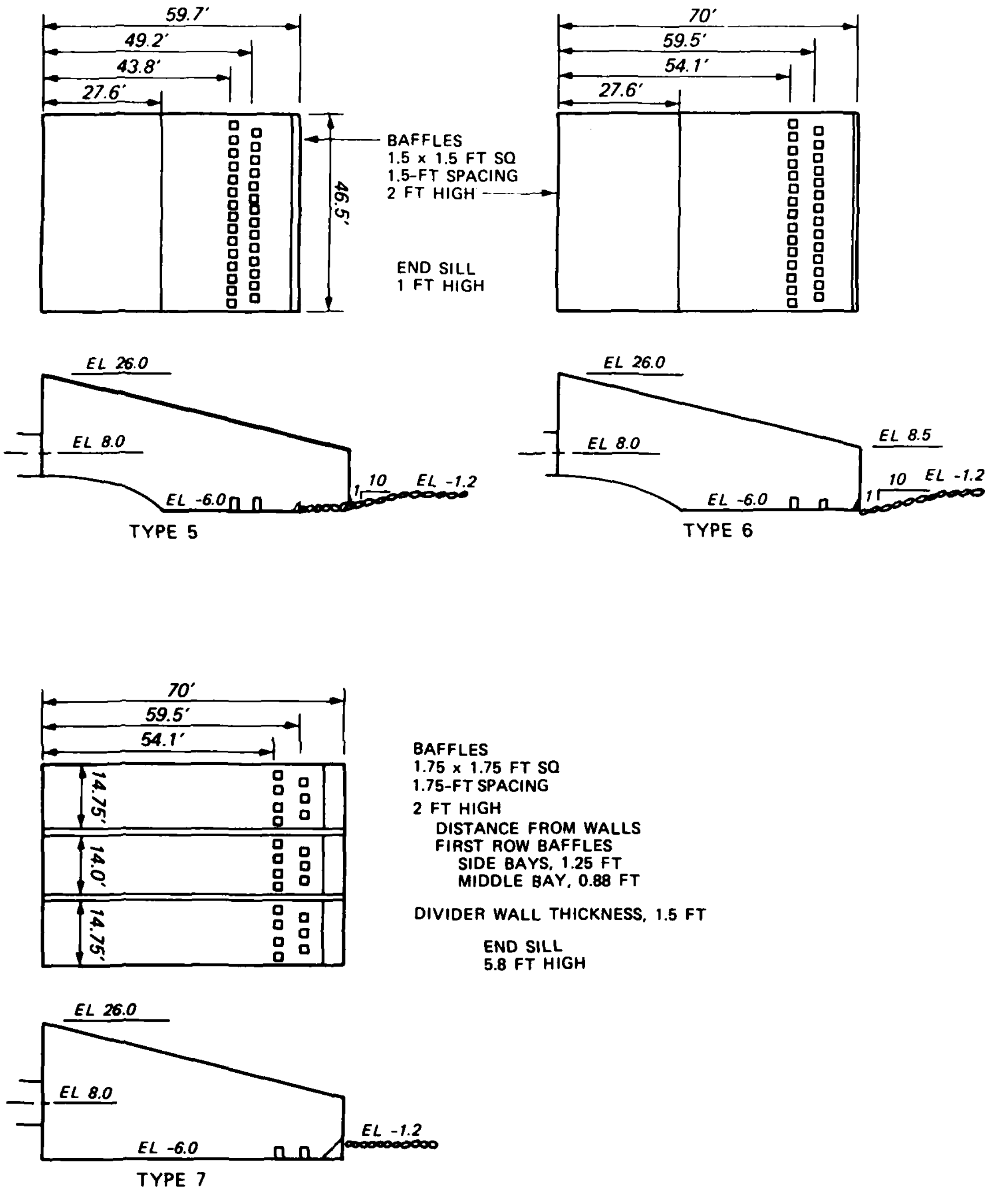


Figure 18. (Concluded)

high and 1.5 ft square with 1.5-ft spacings. The basin apron length was reduced to 33 ft. The 70-ft-long sidewalls were retained so that extensive modifications to the model would not be required in this early phase of the testing. The riprap downstream from the basin did not fail at tailwater el 3.1 when all three pumps were operating; however, when less than three pumps were operating, the efflux was concentrated and the riprap failed. At low tailwaters, flow hitting the baffles was deflected upward causing considerable spray for all pump operating conditions.

43. A second row of baffles was added in the type 3 design stilling basin. The first row of baffles was located 41.6 ft from the backwall and the second row, 44.4 ft from the backwall. The baffles had the same dimensions and spacing as those in the type 2 design stilling basin. The stilling basin length of 50 ft was determined by measuring the trajectory nappe of the flow leaving the outlet pipes and adding an additional distance equal to three times the downstream depth of flow. This distance has been found to work satisfactorily in previous stilling basin studies at WES. The type 3 design stilling basin performance was similar to the type 2 design; the riprap downstream from the basin failed when less than three pumps were operating with tailwater el 3.1. Flow conditions at the low tailwater elevation are shown in Photos 8-10.

44. In order to increase the effective tailwater in the stilling basin, the floor was lowered 3.5 ft to el -6.0 in the type 4 design stilling basin. The basin was also lengthened to 56 ft with two rows of baffles located 40 and 45 ft from the backwall. The baffle dimensions and spacing were the same as in previous designs, but the height of the end sill was reduced to 1.0 ft. This design was based on measurements of the depth of flow leaving the outlet pipes. The measured flow depth was 2 ft, and the corresponding Froude number was 4.1. The downstream or sequent depth required for formation of a hydraulic jump in a horizontal rectangular channel was computed to be 10.5 ft using the following equation:

$$\frac{d_2}{d_1} = \frac{1}{2}\left(-1 + \sqrt{1 + 8F_1^2}\right)$$

where

d_2 = downstream depth

d_1 = upstream depth

F_1 = upstream Froude number = $\frac{V_1}{\sqrt{gd_1}}$

V_1 = average upstream velocity

g = acceleration due to gravity

Previous model studies at WES have shown that the energy head absorbed by the baffles is approximately equal to $0.15d_2$; therefore, the required downstream depth is usually assumed to be $0.85d_2$. Using this value and the minimum tailwater elevation of 3.1, the stilling basin floor was set at el -6.0. The theoretical trajectory of the nappe was calculated using the equation:

$$y = -x \tan \Theta - \frac{gx^2}{2V^2 \cos^2 \Theta}$$

where

y = vertical distance

x = horizontal distance

tan Θ = slope of outlet pipe

g = acceleration due to gravity

V = average velocity leaving outlet pipe

The basin length of 56 ft was determined by adding the trajectory length of the nappe to a distance equal to three times the calculated downstream depth. A 1V-on-10H slope was used downstream of the end sill to transition to the outlet channel invert elevation of -1.2.

45. The stilling action was generally improved with the type 4 design stilling basin, but riprap failure still occurred when less than three pumps were operating at the low tailwater elevation. Return flow swept stones into the basin which could cause considerable concrete abrasion damage. Surface waves downstream from the basin

were observed to be greater when less than three pumps were operating. The deterioration of stilling basin performance as the strength of the flow circulation in the basin increased with two and one pump operation is clearly shown in Photos 11-13. Riprap failure and rock deposited in the basin by single pump operation are shown in Photo 14.

46. In an attempt to eliminate the flow circulation in the basin when less than three pumps were operating, a solid trajectory based on the underside of a free nappe was added between the outlet invert and the type 5 design stilling basin. The parabolic drop was calculated from the formula:

$$y = -x \tan \Theta - \frac{gx^2}{2(1.25V)^2 \cos^2 \Theta}$$

The type 5 design stilling basin trajectory was slightly longer than the theoretical nappe trajectory calculated for the type 4 design stilling basin. This necessitated increasing the basin length to 59.7 ft with two rows of baffles located 43.8 and 49.2 ft from the backwall. The baffle dimensions and spacings were unchanged, and the end sill height remained at 1.0 ft. No significant improvement was observed with the type 5 design stilling basin trajectory.

47. The New Orleans District decided that the stilling basin length should be 70 ft as originally designed. In the type 6 design stilling basin, the type 5 design stilling basin was lengthened to 70 ft and the first and the second row of baffles were positioned 54.1 and 59.5 ft from the backwall. This change had no significant effect on the performance of the stilling basin.

48. In the type 7 design stilling basin the parabolic trajectory was removed and divider walls were added. These walls allowed the energy dissipation from each outlet to take place in essentially separate basins. The width of the two side bays was 14.75 ft and that of the middle bay, 14.0 ft. The baffle row locations with respect to the backwall remained unchanged. The size of the baffles was increased to 1.75 ft square by 2 ft high in order to provide symmetry in location.

The spacing between the baffles was 1.75 ft. Blocks adjacent to a sidewall in the first row of baffles were located 1.25 ft from the wall in the two side bays and 0.88 ft in the middle bay. The height of the 45-deg sloping end sill was increased to 5.8 ft so that the exit channel invert could be returned to el -1.2.

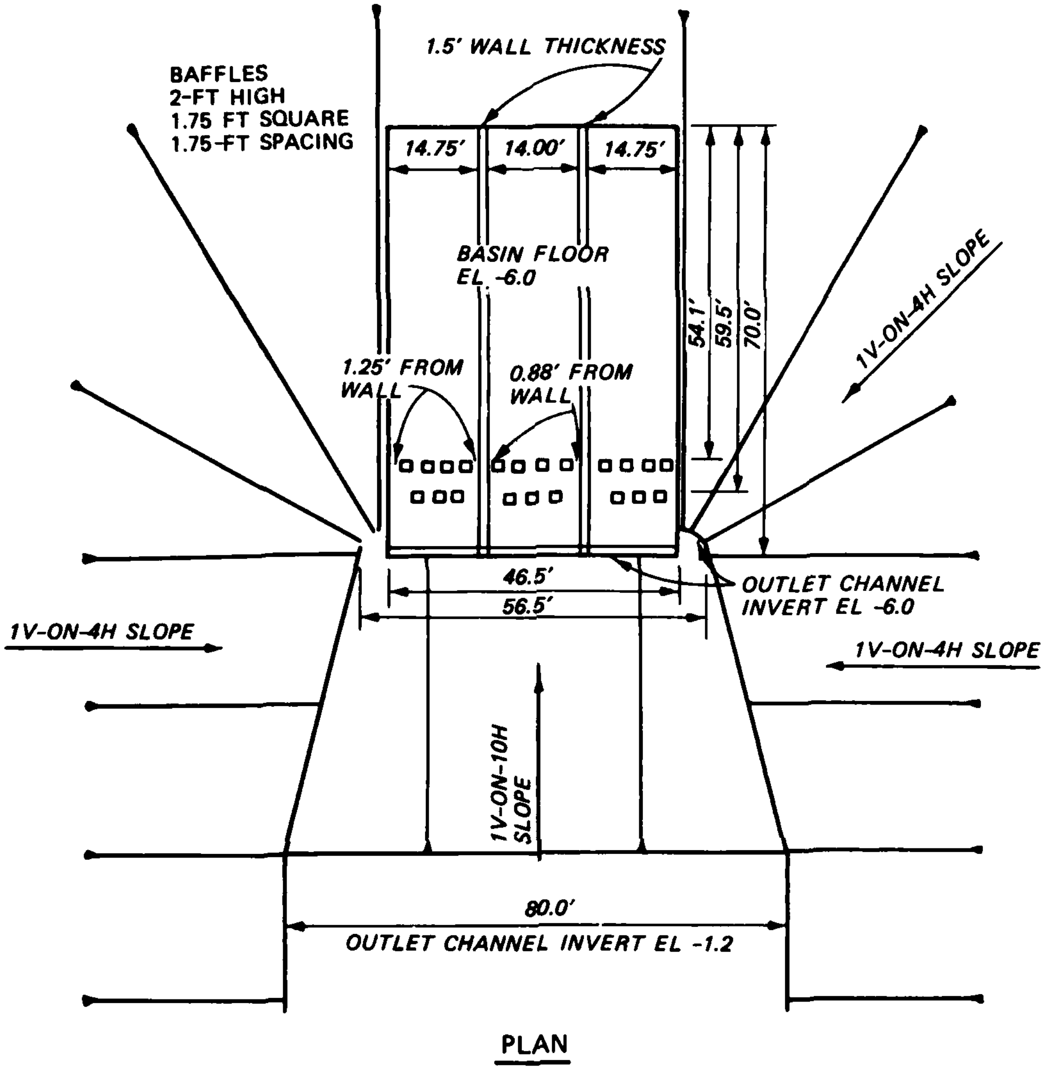
49. With the addition of the divider walls, the problems associated with one and two pump operations were essentially eliminated. Wave action downstream from the basin was still more severe than desirable. Model tests of similar structures at WES have shown that this wave action can be reduced by removing the basin wing walls and allowing wave energy to be dissipated on the slope behind the basin rather than being reflected off the wing wall. Removal of the wing walls would also result in savings. The higher end sill used in the type 7 stilling basin design also caused a small standing wave just downstream from the end sill. Although the riprap was stable during the testing, the standing wave was considered an undesirable feature and could be corrected by installing a less abrupt transition between the stilling basin floor and the outlet channel invert.

Recommended Stilling Basin Design

50. In the type 8 design stilling basin (Figure 19) the wing walls were removed, the discharge pipes were lowered 3.5 ft so that the inverts were at el -0.5, and the end sill height was reduced to 1 ft. The exit channel invert sloped up from el -6.0 to el -1.2 on a 1V-on-10H slope. Flow conditions are shown in Photos 15-18. This design performed satisfactorily under all operating conditions.

Outlet Channel Riprap Protection

51. Riprap protection downstream from the outlet basin was tested in the model study. The original design had a 24-in.-thick riprap blanket for the first 50 ft downstream of the outlet basin, an 18-in.-thick riprap blanket for the next 50 ft, and a 12-in.-thick



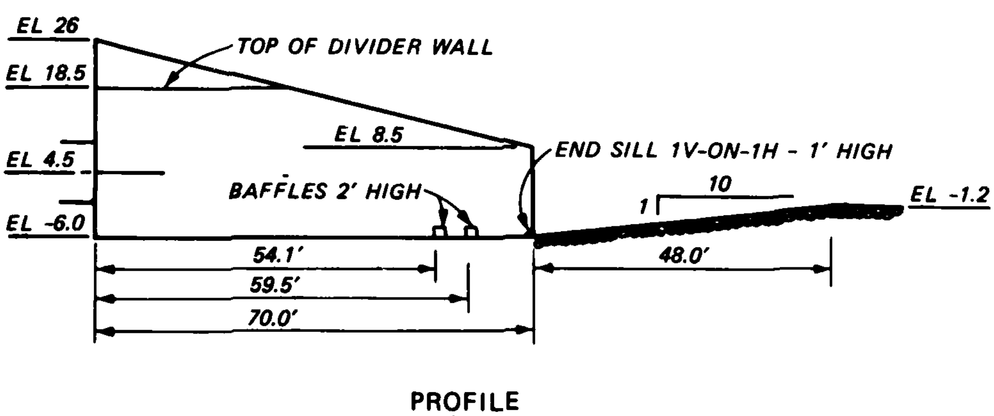


Figure 19. Type 8 stilling basin design

riprap blanket for the next 100 ft. Riprap gradation limits were set according to the guidelines established in Incl 1 of ETL 1110-2-120* for riprap with a specific gravity of 150 pcf. Riprap gradations used in the model are shown in Figure 20.

Percent Lighter by Weight	Riprap Weight, lb 24 in. thick	18 in. thick	12 in. thick
100	628-251	265-106	79-31
50	186-126	79-53	23-16
15	93-39	39-17	12-5

52. The original riprap placement was used throughout the stilling basin testing. After the type 8 design stilling basin was developed and tested with the original riprap, the 24-in.-thick riprap was replaced with 18-in.-thick riprap. The model was operated at tailwater el 3.1 for different combinations of pumps operating for 24 hr (prototype). The 18-in.-thick riprap was found to be adequate. The final recommended riprap plan consisted of 100 ft of 18-in.-thick riprap and 100 ft of 12-in.-thick riprap.

53. The slopes behind the stilling basin were covered with medium sand in the model. There was some erosion and sloughing of these sand slopes due to wave action. It is recommended that the underwater portion of these slopes be protected and that grass be provided on the slope above the riprap to ensure stability. A granular filter should be provided beneath the recommended riprap.

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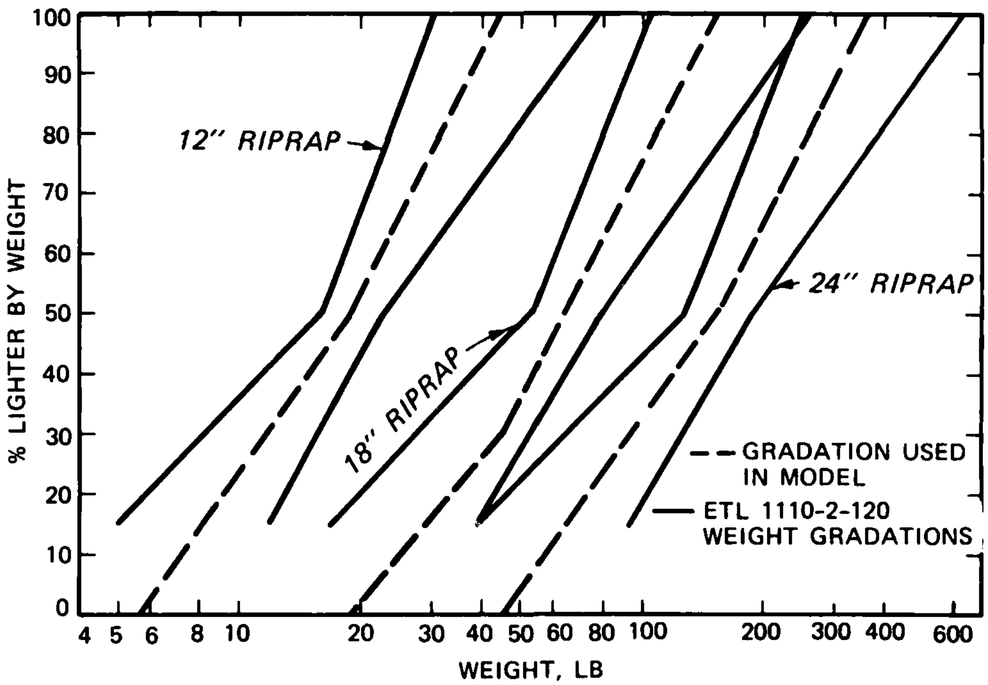
* Office, Chief of Engineers. 1971 (14 May). "Additional Guidance for Riprap Channel Protection," ETL 1110-2-120, Washington, D. C.



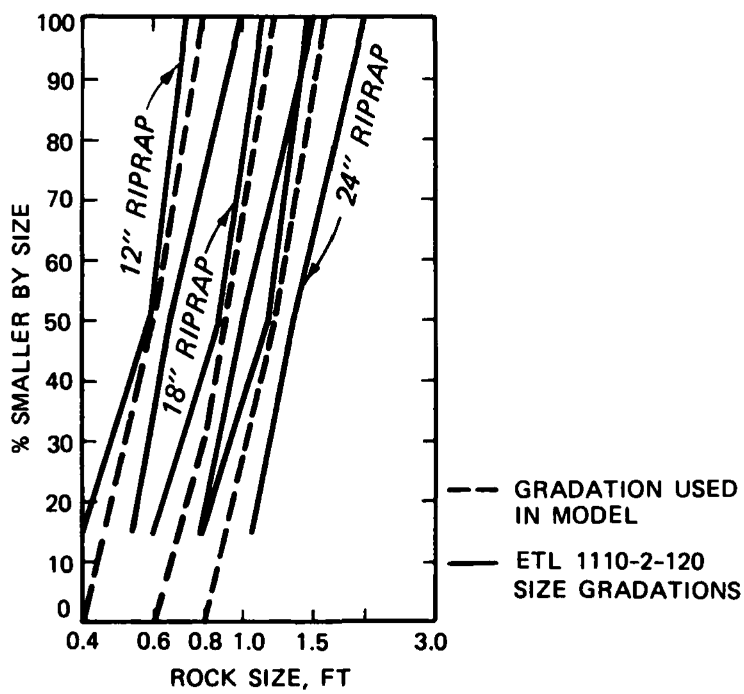


Figure 20. Riprap gradations

PART IV: CONCLUSIONS

54. Satisfactory hydraulic performance can be achieved in a pump sump with low submergence by providing umbrellas on the suction bells, converging sidewalls or wall roughness grids, vortex suppressor beams, and other appurtenances. The umbrellas used herein significantly reduced surface vortices and pressure fluctuations by spreading the flow entering the suction bell. This reduced the magnitude of downward velocities and the effect of uneven approach flow distributions. Converging sidewalls served to streamline the flow lines entering the suction bell, thus reducing swirl and the tendency to form surface vortices. Wall roughness grids accomplished the same result by increasing the turbulence adjacent to the walls, thereby streamlining any adverse velocity distribution entering the sump. Such grids may be difficult to maintain and thus were not included in the recommended design. If either the converging sidewalls or backwall is too close to the suction bell, occasional severe pressure fluctuations or submerged wall vortices will develop. In this model study, the minimum prototype clearance was found to be 9 in. (0.04 times the umbrella diameter). Vortex suppressor beams cause a slight surface turbulence that tends to break up any small vortex that may form in the pump sump. These beams need to be close enough to the backwall so that the turbulence created does not dissipate before reaching areas of vortex formation in the rear of the sump. The best location developed in this model study for the beams was just above the upstream lip of the umbrella. Ideally, the beams should extend approximately 1 ft into the flow. Beams extending much over 1 ft into the flow may disrupt flow patterns in the sump and may cause intermittently severe pressure fluctuations. In a sump with a range of operating water-surface elevations, it is believed that 1-ft beams with 1-ft spacings will create sufficient surface turbulence without disrupting flow patterns during relatively high submergence. Satisfactory sump performance was obtained in the model study with these modifications even for the adverse approach conditions that occur with single pump operations.

55. The approach channel designs tested provided for relatively uniform flow distribution into the sump when all pumps were operating. Any curvature of flow due to the geometry of the approach channel was insignificant when compared with the adverse flow patterns set up when less than all three pumps were operating, and flow had to pass in front of inactive pump bays.

56. A hydraulic jump-type stilling basin can be used to dissipate the energy from the pump station discharge lines. Each outlet pipe should discharge into a separate stilling basin to ensure satisfactory performance when one or more outlets are not discharging. Essentially separate basins can be created by using structurally adequate divider walls. Without these walls, strong circulating currents are set up in the basin which concentrate the flow, reducing energy dissipation against the baffles and end sill. The circulating current can also carry riprap into the basin, and severe concrete abrasion damage may occur. Freestanding sidewalls (no wing walls) provide for more dissipation of wave energy and eddy formations downstream of the stilling basin than do sidewalls with 90-deg wing walls. Standing waves are set up downstream from the stilling basin when the end sill is too high. A shorter end sill with a 1V-on-10H transition slope to the outlet channel invert elevation provides more satisfactory hydraulic performance.

Table 1

Sump Performance, Type 1 Design Sump

Type 1 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	2	-2	±1	±1	0.03	0.01	0.01	A	A	B
20	1	1	2	-2	±1	±2	0.03	0.01	0.03	E	E	E
20	3	25	x	-1	+11	x	0.01	0.16	x	E	D	x
20	18	x	22	+5	x	-17	0.07	x	0.25	E	x	D
20	x	24	1	x	-6	-4	x	0.09	0.06	x	E	E
20	19	x	x	+11	x	x	0.16	x	x	E	x	x
20	x	22	x	x	-9	x	x	0.13	x	x	E	x
20	x	x	26	x	x	-16	x	x	0.23	x	x	E

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.

Discharge 613 cfs per pump.

* See Figure 5, page 16, for explanation of A, B, D, and E.

Table 2

Sump Performance, Type 5 Design Sump

Type 1 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	1	-1	+2	+1	0.01	0.03	0.01	A	A	A
25	2	1	1	-2	+4	-3	0.03	0.06	0.04	A	A	B
24	2	1	2	-1	+1	-4	0.01	0.01	0.06	B	A	B
23	2	1	3	-3	+1	+5	0.04	0.01	0.07	C	C	C
22	2	1	5	-3	0	-5	0.04	0.00	0.07	D	D	D
21	2	1	2	-3	+1	-4	0.04	0.01	0.06	E	E	E
20	2	1	3	-3	+1	-2	0.04	0.01	0.03	E	D	E
20	2	5	x	-1	+17	x	0.01	0.25	x	D	A	x
20	x	5	2	x	-13	-2	x	0.19	0.03	x	E	E
20	2	x	13	+2	x	-13	0.03	x	0.19	D	x	E
20	2	x	x	+3	x	x	0.04	x	x	D	x	x
20	x	2	x	x	+4	x	x	0.06	x	x	B	x
20	x	x	23	x	x	-14	x	x	0.20	x	x	E

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.

Discharge 613 cfs per pump; temperature 62°F.

* See Figure 5, page 16, for explanation of A, B, C, D, and E.

Table 3

Sump Performance, Type 6 Design Sump

Type 1 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	-3	0	+2	0.04	0.00	0.03	A	A	A
25	2	1	2	-2	$\pm$1	-3	0.03	0.01	0.04	B	A	A
24	1	1	2	-2	-3	-3	0.03	0.04	0.04	B	D	B
23	1	1	1	-3	-1	-4	0.04	0.01	0.06	D	D	D
22	1	1	1	-4	+1	-3	0.06	0.01	0.04	D	D	D
21	1	1	1	-5	+1	-4	0.07	0.01	0.06	C	C	C
20	2	1	1	-2	+1	-2	0.03	0.01	0.03	D	D	D
20	1	2	x	-2	+15	x	0.03	0.22	x	D	D	x
20	1	x	3	-2	x	-5	0.03	x	0.07	D	x	E
20	x	7	1	x	-9	-5	x	0.13	0.07	x	D	E
20	1	x	x	+5	x	x	0.07	x	x	E	x	x
20	x	1	x	x	+1	x	x	0.01	x	x	E	x
20	x	x	23	x	x	-16	x	x	0.23	x	x	E

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and $\pm$ = swirl direction intermittent.

Discharge 613 cfs per pump, temperature 55°F.

* See Figure 5, page 16, for explanation of A, B, C, D, and E.

Table 4

Sump Performance, Type 7 Design Sump

Type 1 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	16	7	8	-3	+3	±1	0.04	0.04	0.01	A	A	A
25	11	2	2	-3	+3	+1	0.04	0.04	0.01	A	A	A
24	12	6	5	-4	0	-1	0.06	0.00	0.01	A	A	A
23	17	5	2	-5	+1	0	0.07	0.01	0.00	A	A	A
22	10	2	11	-3	+1	-2	0.04	0.01	0.03	A	B	A
21	13	2	8	-5	+4	+5	0.07	0.06	0.07	B	A	B
20	14	17	14	-5	+4	+5	0.07	0.06	0.07	B	B	B
20	3	22	x	-2	+12	x	0.03	0.17	x	B	D	x
20	13	x	28	+3	x	-9	0.04	x	0.13	B	x	B
20	x	17	22	x	-8	-6	x	0.12	0.09	x	D	D
20	4	x	x	+5	x	x	0.07	x	x	D	x	x
20	x	2	x	x	-2	x	x	0.03	x	x	D	x
20	x	x	25	x	x	-11	x	x	0.16	x	x	C

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump, temperature 54°F.

* See Figure 5, page 16, for explanation of A, B, C and D.

Table 5

Sump Performance, Type 7 Design Sump

Type 2 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	6	15	6	-2	+2	+1	0.03	0.03	0.01	A	A	A
25	7	11	2	-2	+3	+0	0.03	0.04	0.00	A	B	A
24	3	12	3	-2	+3	-1	0.03	0.04	0.01	A	B	B
23	8	10	3	-1	+1	-1	0.01	0.01	0.01	B	B	B
22	4	6	1	-1	+3	±1	0.01	0.04	0.01	B	B	D
21	2	10	2	-1	+4	+1	0.01	0.06	0.01	A	B	A
20	7	10	16	-3	+3	-4	0.04	0.04	0.06	A	D	B
20	4	13	x	-3	+11	x	0.06	0.16	x	A	D	x
20	7	x	10	+2	x	-6	0.03	x	0.09	B	x	D
20	x	22	14	x	-6	-5	x	0.09	0.07	x	B	D
20	3	x	x	+3	x	x	0.04	x	x	B	x	x
20	x	3	x	x	+2	x	x	0.03	x	x	B	x
20	x	x	21	x	x	-9	x	x	0.13	x	x	B

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.

Discharge 613 cfs per pump.

* See Figure 5, page 16, for explanation of A, B, and D.

Table 6

Sump Performance, Type 8 Design Sump

Type 1 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	2	-5	+2	+3	0.07	0.03	0.04	A	A	A
25	5	2	3	-6	+1	+2	0.09	0.01	0.03	A	B	B
24	5	2	2	-6	+2	+2	0.09	0.03	0.03	A	B	B
23	12	2	12	-4	+3	+1	0.06	0.04	0.01	A	B	B
22	8	2	6	-4	+4	-2	0.06	0.06	0.03	A	B	B
21	5	2	3	-4	±1	-3	0.06	0.01	0.04	B	B	B
20	2	2	9	-3	+1	+2	0.04	0.01	0.03	B	B	B
20	2	9	x	-3	+10	x	0.04	0.14	x	B	B	x
20	2	x	4	+2	x	-6	0.03	x	0.09	B	x	B
20	x	20	2	x	-8	-3	x	0.12	0.04	x	B	B
20	3	x	x	-6	x	x	0.09	x	x	B	x	x
20	x	1	x	x	-4	x	x	0.06	x	x	B	x
20	x	x	18	x	x	-7	x	x	0.10	x	x	B

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump.
* See Figure 5, page 16, for explanation of A and B.

Table 7

Sump Performance, Type 9 Design Sump

Type 1 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	3	4	6	0	+3	-1	0.00	0.04	0.01	0	0	0
25	2	8	9	0	+2	-1	0.00	0.03	0.01	0	0	0
24	2	8	7	0	+2	-1	0.00	0.03	0.01	0 SW	0 SW	0 SW
23	2	7	7	0	+2	±1	0.00	0.03	0.01	0 SW	A	0 SW
22	5	6	6	0	+3	-1	0.00	0.04	0.01	A SW	A SW	A SW
21	5	5	8	+1	+3	-1	0.01	0.04	0.01	A SW	A SW	A
20	3	6	8	+1	+3	-1	0.01	0.04	0.01	A SW	B	A SW
20	3	4	x	+1	+1	x	0.01	0.01	x	A	A	x
20	5	x	6	-1	x	-1	0.01	x	0.01	A SW	x	A SW
20	x	4	8	x	+1	-1	x	0.01	0.01	x	A	A
20	3	x	x	-1	x	x	0.01	x	x	A SW	x	x
20	x	8	x	x	+3	x	x	0.04	x	x	A SW	x
20	x	x	6	x	x	-1	x	x	0.01	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
SW = Sidewall vortex.
Discharge 613 cfs per pump, temperature 55°F.
* See Figure 5, page 16, for explanation of A and B.

Table 8

Sump Performance, Type 9 Design Sump

Type 2 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	3	6	4	0	+2	+1	0.00	0.03	0.01	A SW	A SW	A SW
25	3	5	3	+1	+2	-1	0.01	0.03	0.01	A SW	A SW	A SW
24	6	6	4	+1	+2	-1	0.01	0.03	0.01	A SW	A SW	A SW
23	5	6	4	+1	+2	-1	0.01	0.03	0.01	A SW	A SW	A SW
22	4	8	4	+2	-1	-2	0.03	0.01	0.03	A SW	A SW	A SW
21	5	6	5	-2	+3	-2	0.03	0.04	0.03	A SW	A SW	A SW
20	4	8	5	-2	-2	-2	0.03	0.03	0.03	A SW	A SW	A SW
20	4	4	x	-1	0	x	0.01	0.00	x	A SW	A SW	x
20	4	x	6	-1	x	0	0.01	x	0.00	A SW	x	A SW
20	x	2	4	x	0	0	x	0.00	0.00	x	A SW	A SW
20	3	x	x	-1	x	x	0.01	x	x	B	x	x
20	x	10	x	x	+2	x	x	0.03	x	x	B	x
20	x	x	3	x	x	-1	x	x	0.01	x	x	B

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
SW = sidewall vortex.
Discharge 613 cfs per pump.
* See Figure 5, page 16, for explanation of A and B.

Table 9

Sump Performance, Type 10 Design Sump

Type 2 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	4	-3	+1	-1	0.04	0.01	0.01	A	A	A
25	2	1	2	-2	+2	-1	0.03	0.03	0.01	A	A	A
24	2	1	1	-2	+2	+2	0.03	0.03	0.03	A	B	B
23	2	1	2	-2	+2	+2	0.03	0.03	0.03	A	D	B
22	2	1	9	-2	+2	+2	0.03	0.03	0.03	B	D	B
21	2	2	4	-2	+2	±1	0.03	0.03	0.01	B	D	D
20	2	1	8	-3	-1	-4	0.04	0.01	0.06	B	D	D
20	2	9	x	-3	+9	x	0.04	0.13	x	D	D	x
20	2	x	16	+2	x	-8	0.03	x	0.12	0	x	D
20	x	8	15	x	-8	-5	x	0.12	0.07	x	D	D
20	2	x	x	+1	x	x	0.01	x	x	A	x	x
20	x	2	x	x	-1	x	x	0.01	x	x	D	x
20	x	x	6	x	x	-8	x	x	0.12	x	x	D

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump, temperature 56°F.
* See Figure 5, page 16, for explanation of A, B, and D.

Table 10

Sump Performance, Type 11 Design Sump

Type 2 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	2	-1	+3	-2	0.01	0.04	0.03	A	B	A
25	2	1	2	-2	+1	-3	0.03	0.01	0.04	B	B	B
24	2	1	3	-1	+1	-4	0.01	0.01	0.06	B	B	B
23	2	1	2	-2	+1	-3	0.03	0.01	0.04	B	B	D
22	2	1	2	-2	+1	-3	0.03	0.01	0.04	B	D	D
21	2	1	2	-2	+1	-2	0.03	0.01	0.03	D	D	D
20	2	1	15	-4	+2	-5	0.06	0.03	0.07	B	B	B
20	2	4	x	-2	+11	x	0.03	0.16	x	A	B	x
20	1	x	15	+4	x	-10	0.06	x	0.14	B	x	D
20	x	19	5	x	-9	+8	x	0.13	0.12	x	D	B
20	9	x	x	+6	x	x	0.09	x	x	B	x	x
20	x	1	x	x	-2	x	x	0.03	x	x	B	x
20	x	x	10	x	x	-11	x	x	0.16	x	x	B

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.

Discharge 613 cfs per pump, temperature 55°F.

* See Figure 5, page 16, for explanation of A, B, and D.

Table 11

Sump Performance, Type 11 Design Sump

Type 3 Design Approach Channel

Elevation	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
ft NGVD	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	2	-2	+1	-1	0.03	0.01	0.01	A	A	A
25	2	1	1	-1	+2	-2	0.01	0.03	0.03	A	B	A
24	4	1	6	-1	+2	-3	0.01	0.03	0.04	A	B	D
23	2	1	4	-2	+1	-2	0.03	0.01	0.03	A	D	D
22	1	1	2	-1	+1	-4	0.01	0.01	0.06	A	D	D
21	3	4	2	0	+1	+4	0.00	0.01	0.06	B	D	D
20	5	2	4	-6	+1	-7	0.09	0.01	0.10	D	D	D
20	4	9	x	-4	+7	x	0.06	0.10	x	D	D	x
20	18	x	11	+6	x	-10	0.09	x	0.14	D	x	D
20	x	17	4	x	-10	-7	x	0.14	0.10	x	D	D
20	27	x	x	+11	x	x	0.16	x	x	E	x	x
20	x	1	x	x	±2	x	x	0.03	x	x	E	x
20	x	x	22	x	x	-16	x	x	0.23	x	x	E

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump.
* See Figure 5, page 16, for explanation of A, B, D, and E.

Table 12

Sump Performance, Type 11 Design Sump

Type 3 Design Approach Channel

(Cooling Water System Off)

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
20	3	2	3	-3	±2	-3	0.04	0.03	0.04	D	D	D
20	1	12	x	-1	+12	x	0.01	0.17	x	D	D	x
20	3	x	7	+3	x	-7	0.04	x	0.10	D	x	D
20	x	20	2	x	-20	-2	x	0.29	0.03	x	D	D
20	16	x	x	+16	x	x	0.23	x	x	E	x	x
20	x	1	x	x	+1	x	x	0.01	x	x	E	x
20	x	x	14	x	x	-14	x	x	0.20	x	x	E

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.

Discharge 613 cfs per pump, temperature 63°F.

* See Figure 5, page 16, for explanation of D and E.

Table 13

Sump Performance, Type 12 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	11	6	12	0	0	0	0.00	0.00	0.00	A	A	A
25	9	12	8	0	+1	0	0.00	0.01	0.00	A SW	A	A
24	9	5	9	0	0	0	0.00	0.00	0.00	B	B	A
23	8	7	14	0	0	0	0.00	0.00	0.00	A	B	B
22	8	7	4	0	0	0	0.00	0.00	0.00	B	B	B
21	15	5	5	-1	0	0	0.01	0.00	0.00	D	B	D
20	6	4	4	-2	0	0	0.03	0.00	0.00	D	D	D
20	7	3	x	-1	+4	x	0.01	0.06	x	D	D	x
20	8	x	4	0	x	-2	0.00	x	0.03	D	x	D
20	x	2	7	x	-2	0	x	0.03	0.00	x	D	D
20	10	x	x	-1	x	x	0.01	x	x	D	x	x
20	x	9	x	x	0	x	x	0.00	x	x	D	x
20	x	x	3	x	x	-1	x	x	0.01	x	x	D

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
SW = Sidewall vortex.
Discharge 613 cfs per pump, temperature 63°F.
* See Figure 5, page 16, for explanation of A, B, and D.

Table 14

Sump Performance, Type 13 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	3	2	2	-1	+2	-2	0.01	0.03	0.03	0 FV	0 FV	0 FV
25	3	2	2	-2	+3	-2	0.03	0.04	0.03	0 FV	0 FV	0 FV
24	2	2	2	-1	+2	-2	0.01	0.03	0.03	A FV	A FV	A FV
23	2	2	2	-1	+2	-2	0.01	0.03	0.03	A FV	A FV	A FV
22	2	2	2	-1	+2	-2	0.01	0.03	0.03	A FV	A FV	A FV
21	2	3	2	0	+1	-1	0.00	0.01	0.01	B	B	B
20	3	1	2	0	+1	-1	0.00	0.01	0.01	B	B	D
20	7	1	x	-2	+3	x	0.03	0.04	x	D	D	x
20	3	x	1	0	x	-4	0.00	x	0.06	D	x	D
20	x	1	2	x	-4	-1	x	0.06	0.01	x	D	D
20	4	x	x	-1	x	x	0.01	x	x	B	x	x
20	x	2	x	x	+1	x	x	0.01	x	x	D	x
20	x	x	1	x	x	-5	x	x	0.07	x	x	D

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
FV = floor vortex.
Discharge 613 cfs per pump, temperature 59°F.
* See Figure 5, page 16, for explanation of A, B, and D.

Table 15

Sump Performance, Type 14 Design Sump

Type 3 Design Approach Channel

Elevation	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
ft NGVD	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	-2	-1	-1	0.03	0.01	0.01	A	A	A
25	2	1	1	-2	0	-1	0.03	0.00	0.01	A	A	A
24	2	1	1	-2	0	-1	0.03	0.00	0.01	A	A	A
23	2	1	1	-2	±1	-1	0.03	0.01	0.01	A	A	A
22	2	1	1	-2	+2	-1	0.03	0.03	0.01	A	A	A
21	2	1	1	-3	+3	-1	0.04	0.04	0.01	A	A	A
20	1	1	1	-1	0	-3	0.01	0.00	0.04	A	A	A
20	2	4	x	-1	+17	x	0.01	0.25	x	A	A	x
20	2	x	16	+3	x	-18	0.04	x	0.26	A	x	A
20	x	6	1	x	+7	+4	x	0.10	0.06	x	A	A
20	2	x	x	+2	x	x	0.03	x	x	A	x	x
20	x	1	x	x	+6	x	x	0.09	x	x	A	x
20	x	x	4	x	x	+9	x	x	0.13	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump, temperature 62°F.

* See Figure 5, page 16, for explanation of A.

Table 16

Sump Performance, Type 15 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
20	7	1	1	-13	±2	±3	0.19	0.03	0.04	A	A	A
20	3	4	x	±2	-11	x	0.03	0.16	x	A	A	x
20	3	x	3	-5	x	+12	0.07	x	0.17	A	x	A
20	x	4	2	x	-6	-4	x	0.09	0.06	x	A	A
20	26	x	x	+10	x	x	0.14	x	x	A	x	x
20	x	1	x	x	+2	x	x	0.03	x	x	A	x
20	x	x	5	x	x	-10	x	x	0.14	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump.
* See Figure 5, page 16, for explanation of A.

Table 17

Sump Performance, Type 16 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	0	+1	-3	0.00	0.01	0.04	0	0	0
25	1	1	2	-1	+1	-7	0.01	0.01	0.10	0	0	0
24	1	1	1	-1	+2	-7	0.01	0.03	0.10	0	0	0
23	1	1	1	-2	±1	-1	0.03	0.01	0.01	0	0	0
22	1	1	1	-1	+1	-1	0.01	0.01	0.01	0	0	0
21	1	1	1	±1	±2	-1	0.01	0.03	0.01	0	0	0
20	1	1	1	-1	±3	-1	0.01	0.04	0.01	0	0	0
20	2	2	x	-1	+4	x	0.01	0.06	x	0	0	x
20	2	x	2	-2	x	+1	0.03	x	0.01	0	x	0
20	x	1	0	x	+3	-1	x	0.04	0.01	x	0	0
20	2	x	x	-4	x	x	0.06	x	x	0	x	x
20	x	1	x	x	+1	x	x	0.01	x	x	0	x
20	x	x	1	x	x	-2	x	x	0.03	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump, temperature 67°F.

Table 18

Sump Performance, Type 17 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	1	-2	+1	-1	0.03	0.01	0.01	A	A	A
25	2	2	2	-2	+1	-1	0.03	0.01	0.01	B	A	A
24	2	1	1	-2	+1	-1	0.03	0.01	0.01	B	A	A
23	2	1	1	-2	+1	-1	0.03	0.01	0.01	A	A	A
22	2	1	1	-2	+1	-1	0.03	0.01	0.01	A	A	A
21	2	1	1	-1	+1	-1	0.01	0.01	0.01	A	A	A
20	2	1	2	-1	+1	-1	0.01	0.01	0.01	A	A	A
20	2	3	x	-1	+4	x	0.01	0.06	x	A	B	x
20	2	x	2	0	x	-2	0.00	x	0.03	A	x	A
20	x	1	1	x	-1	-1	x	0.01	0.01	x	A	A
20	3	x	x	-1	x	x	0.01	x	x	A	x	x
20	x	1	x	x	+1	x	x	0.01	x	x	A	x
20	x	x	1	x	x	-3	x	x	0.04	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump.
* See Figure 5, page 16, for explanation of A and B.

Table 19

Sump Performance, Type 18 Design Sump

Type 3 Design Approach Channel

Elevation	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
ft NGVD	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	2	1	-3	+2	+1	0.04	0.03	0.01	A	0	0
25	2	1	1	-2	+2	+1	0.03	0.03	0.01	A	A	0
24	2	1	2	-3	+1	+1	0.04	0.01	0.01	A	A	A
23	1	1	1	-3	+2	+1	0.04	0.03	0.01	A	A	A
22	1	1	1	-3	+1	+1	0.04	0.01	0.01	A	A	A
21	1	1	1	-3	+1	+1	0.04	0.01	0.01	B	A	B
20	2	1	1	-2	+1	+1	0.03	0.01	0.01	B	B	B
20	1	2	x	-2	+6	x	0.03	0.09	x	B	B	x
20	1	x	1	-2	x	0	0.03	x	0.00	A	x	B
20	x	1	1	x	-3	0	x	0.04	0.00	x	B	B
20	2	x	x	+1	x	x	0.01	x	x	B	x	x
20	x	1	x	x	+1	x	x	0.01	x	x	B	x
20	x	x	1	x	x	-3	x	x	0.04	x	x	B

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and $\pm$ = swirl direction intermittent.
Discharge 613 cfs per pump, temperature 76°F.
* See Figure 5, page 16, for explanation of A and B.

Table 20

Sump Performance, Type 19 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
25	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
24	2	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
23	3	5	7	-1	+2	0	0.01	0.03	0.00	0	0	0
22	2	1	5	±1	-2	±1	0.01	0.03	0.01	0	0	0
21	6	2	1	±1	-2	0	0.01	0.03	0.00	0	0	0
20	2	2	2	-1	+2	-1	0.01	0.03	0.01	0	0	0
20	2	1	x	-1	+2	x	0.01	0.03	x	A	0	x
20	2	x	1	-1	x	-1	0.01	x	0.01	0	x	0
20	x	4	1	x	+2	-1	x	0.03	0.01	x	A	A
20	2	x	x	-1	x	x	0.01	x	x	A	x	x
20	x	1	x	x	0	x	x	0.00	x	x	A	x
20	x	x	9	x	x	0	x	x	0.00	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 613 cfs per pump. temperature 62°F.
* See Figure 5, page 16, for explanation of A.

Table 21

Sump Performance, Type 20 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water Bay 1	Bay 2	Bay 3	Swirl: Vortimeter Revolutions per Minute Bay 1	Bay 2	Bay 3	Swirl: Rotational Flow Indicator Bay 1	Bay 2	Bay 3	Vortex Development* Bay 1	Bay 2	Bay 3
26	1	1	1	0	+1	-1	0.00	0.01	0.01	B	B	A
25	1	1	1	0	+1	-1	0.00	0.01	0.01	B	B	A
24	1	1	1	-1	+2	-1	0.01	0.03	0.01	B	B	A
23	1	1	1	0	+2	-1	0.00	0.03	0.01	B	B	B
22	1	1	1	±1	+3	0	0.01	0.04	0.00	B	B	B
21	1	1	1	-1	+2	+1	0.01	0.03	0.01	B	B	B
20	2	1	1	0	+3	0	0.00	0.04	0.00	B	B	B
20	1	2	x	0	+1	x	0.00	0.01	x	B	B	x
20	1	x	1	+2	x	-3	0.03	x	0.04	B	x	B
20	x	1	2	x	-1	-1	x	0.01	0.01	x	B	B
20	2	x	x	+1	x	x	0.01	x	x	B	x	x
20	x	2	x	x	+4	x	x	0.05	x	x	B	x
20	x	x	1	x	x	-4	x	x	0.05	x	x	B

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 70°F.

* See Figure 5, page 16, for explanation of A and B.

Table 22

Sump Performance, Type 21 Design Sump

Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	0	0	0	0.00	0.00	0.00	B	B	B
25	1	1	1	0	+2	-1	0.00	0.03	0.01	B	B	B
24	1	1	1	-1	+2	0	0.01	0.03	0.00	A	A	A
23	1	1	1	-2	+2	0	0.03	0.03	0.00	A	A	A
22	1	1	1	0	+4	-1	0.00	0.05	0.01	0	0	0
21	1	1	1	0	+2	-2	0.00	0.03	0.03	0	0	0
20	1	1	1	-1	+2	-1	0.01	0.03	0.01	0	0	0
20	1	1	x	0	+5	x	0.00	0.06	x	A	A	x
20	3	x	1	+1	x	-2	0.01	x	0.03	A	x	A
20	x	1	1	x	-1	-2	x	0.01	0.03	x	A	0
20	1	x	x	+2	x	x	0.03	x	x	A	x	x
20	x	1	x	x	+2	x	x	0.03	x	x	A	x
20	x	x	1	x	x	-4	x	x	0.05	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 77-86°F.
* See Figure 5, page 16, for explanation of A and B.

Table 23

Sump Performance; Bay 1 Type 22 Design Sump, Bay 2 Type 23 Design Sump, Bay 3 Type 24 Design Sump; Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	6	-1	+3	0	0.01	0.04	0.00	0	0	0
25	1	1	6	0	+2	0	0.00	0.03	0.00	0	0	A
24	1	1	1	±2	+2	0	0.03	0.03	0.00	0	A	A
23	1	1	1	0	+2	0	0.00	0.03	0.00	A	A	A
22	1	1	1	0	+3	0	0.00	0.04	0.00	0	0	0
21	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
20	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
20	1	2	x	0	+7	x	0.00	0.09	x	0	A	x
20	1	x	1	0	x	-2	0.00	x	0.03	0	x	0
20	x	1	1	x	-1	-1	x	0.01	0.01	x	0	0
20	1	x	x	+1	x	x	0.01	x	x	A	x	x
20	x	1	x	x	+2	x	x	0.03	x	x	0	x
20	x	x	1	x	x	-4	x	x	0.05	x	x	A

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 77-81°F.
* See Figure 5, page 16, for explanation of A.

Table 24

Sump Performance; Bay 1 Type 25 Design Sump, Bay 2 Type 26 Design Sump, Bay 3 Type 27 Design Sump; Type 3 Design Approach Channel

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	-1	+4	0	0.01	0.05	0.00	A	0	0
25	1	1	1	0	+4	-1	0.00	0.05	0.01	0	0	0
24	1	1	1	0	+4	0	0.00	0.05	0.00	0	0	0
23	1	1	1	0	+4	0	0.00	0.05	0.00	0	0	0
22	1	3	1	0	+4	0	0.00	0.05	0.00	0	0	0
21	1	1	1	-1	+3	0	0.01	0.04	0.00	0	0	0
20	1	5	1	0	+4	0	0.00	0.05	0.00	0	0	0
20	1	8	x	0	+5	x	0.00	0.06	x	0	0	x
20	2	x	1	-1	x	-2	0.01	x	0.03	0	x	0
20	x	3	1	x	+3	-1	x	0.04	0.01	x	0	0
20	1	x	x	0	x	x	0.00	x	x	0	x	x
20	x	2	x	x	+4	x	x	0.05	x	x	0	x
20	x	x	1	x	x	-2	x	x	0.03	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 81°F.
* See Figure 5, page 16, for explanation of A.

Table 25

Sump Performance, Type 27 Design Sump

Type 3 Design Approach Channel

Elevation	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
ft NGVD	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	2	±1	+3	0	0.01	0.04	0.00	0	0	0
25	1	2	2	-1	+2	0	0.01	0.03	0.00	0	0	0
24	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
23	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
22	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
21	1	3	1	0	+3	0	0.00	0.04	0.00	0	0	0
20	1	1	1	0	+2	0	0.00	0.03	0.00	0	0	0
20	1	1	x	0	+4	x	0.00	0.05	x	0	0	x
20	2	x	2	0	x	-1	0.00	x	0.01	0	x	0
20	x	1	1	x	+1	-2	x	0.01	0.03	x	0	0
20	1	x	x	0	x	x	0.00	x	x	0	x	x
20	x	1	x	x	+3	x	x	0.04	x	x	0	x
20	x	x	1	x	x	-2	x	x	0.03	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 84°F.

Table 26

Sump Performance, Type 25 Design Sump, Type 1 Design Approach Channel, Type 1 Design Umbrella Supports

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	2	1	-1	+3	0	0.01	0.04	0.00	0	0	0
25	1	2	1	-1	+3	0	0.01	0.04	0.00	0	0	0
24	1	1	1	-1	+3	0	0.01	0.04	0.00	0	0	0
23	1	1	1	±1	+2	0	0.01	0.03	0.00	0	0	0
22	1	1	1	0	+3	0	0.00	0.04	0.00	0	0	0
21	1	1	1	±1	+2	0	0.01	0.03	0.00	0	0	0
20	1	2	1	-1	+2	0	0.01	0.03	0.00	0	0	0
20	2	2	x	-1	+4	x	0.01	0.05	x	0	0	x
20	2	x	1	0	x	-1	0.00	x	0.01	0	x	0
20	x	1	1	x	0	-1	x	0.00	0.01	x	0	0
20	1	x	x	0	x	x	0.00	x	x	0	x	x
20	x	2	x	x	+2	x	x	0.03	x	x	0	x
20	x	x	1	x	x	-3	x	x	0.04	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 78°F.

Table 27

Sump Performance, Type 25 Design Sump, Type 1 Design Approach Channel, Type 1 Design Umbrella Supports

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	2	1	0	+2	-1	0.00	0.03	0.01	0	0	0
25	2	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
24	2	1	1	0	+1	-1	0.00	0.01	0.01	0	0	0
23	2	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
22	2	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
21	2	1	1	0	-1	+1	0.00	0.01	0.01	0	0	0
20	1	1	1	0	+1	-2	0.00	0.01	0.03	0	0	0
20	2	1	x	+1	+2	x	0.01	0.03	x	0	0	x
20	2	x	1	-3	x	+1	0.04	x	0.01	0	x	0
20	x	1	1	x	±1	-2	x	0.01	0.03	x	0	0
20	2	x	x	-2	x	x	0.03	x	x	0	x	x
20	x	1	x	x	-2	x	x	0.03	x	x	0	x
20	x	x	3	x	x	-3	x	x	0.04	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump.
Same design as Table 26 tested one year later.

Table 28

Sump Performance, Type 25 Design Sump, Type 1 Design Approach Channel, Type 2 Design Umbrella Supports

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	2	0	+2	0	0.00	0.03	0.00	0	0	0
25	1	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
24	1	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
23	1	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
22	1	1	2	0	+1	0	0.00	0.01	0.00	0	0	0
21	2	1	2	-1	+1	0	0.01	0.01	0.00	0	0	0
20	1	1	2	-2	0	-2	0.03	0.00	0.03	0	0	0
20	1	1	x	-1	+3	x	0.01	0.04	x	0	0	x
20	1	x	2	-1	x	-2	0.01	x	0.03	0	x	0
20	x	1	3	x	-1	-3	x	0.01	0.04	x	0	0
20	2	x	x	0	x	x	0.00	x	x	0	x	x
20	x	1	x	x	+1	x	x	0.01	x	x	0	x
20	x	x	4	x	x	-3	x	x	0.04	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and $\pm$ = swirl direction intermittent.
Discharge 680 cfs per pump.

Table 29

Sump Performance, Type 25 Design Sump, Type 1 Design Approach Channel, Type 3 Design Umbrella Supports

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
25	2	1	2	0	+1	0	0.00	0.01	0.00	0	0	0
24	2	1	2	0	+1	0	0.00	0.01	0.00	0	0	0
23	2	1	2	0	+1	0	0.00	0.01	0.00	0	0	0
22	2	1	2	0	+1	0	0.00	0.01	0.00	0	0	0
21	1	1	1	0	+1	0	0.00	0.01	0.00	0	0	0
20	2	1	1	-1	+1	-2	0.01	0.01	0.03	0	0	0
20	1	1	x	0	+3	x	0.00	0.04	x	0	0	x
20	2	x	1	0	x	-3	0.00	x	0.04	0	x	0
20	x	1	1	x	-1	-3	x	0.01	0.04	x	0	0
20	1	x	x	0	x	x	0.00	x	x	0	x	x
20	x	1	x	x	+2	x	x	0.03	x	x	0	x
20	x	x	2	x	x	-1	x	x	0.01	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 66-76°F.

Table 30

Sump Performance, Type 28 Design Sump, Type 1 Design Approach Channel, Type 2 Design Umbrella Supports

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	2	1	1	±1	+2	0	0.01	0.03	0.00	0	0	0
25	2	1	1	-1	+2	±1	0.01	0.03	0.01	0	0	0
24	2	1	1	0	+2	-1	0.00	0.03	0.01	0	0	0
23	2	1	1	-1	-1	0	0.01	0.01	0.00	0	0	0
22	2	2	1	0	+2	0	0.00	0.03	0.00	0	0	0
21	2	2	1	0	+2	±1	0.00	0.03	0.01	0	0	0
20	2	2	1	-1	+1	-1	0.01	0.01	0.01	0	0	0
20	2	2	x	-1	+4	x	0.01	0.05	x	0	0	x
20	2	x	2	±1	x	-1	0.01	x	0.01	0	x	0
20	x	2	2	x	0	-2	x	0.00	0.03	x	0	0
20	2	x	x	-1	x	x	0.01	x	x	0	x	x
20	x	2	x	x	0	x	x	0.00	x	x	0	x
20	x	x	2	x	x	-1	x	x	0.01	x	x	0

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 71-76°F.

Table 31

Sump Performance, Type 28 Design Sump, Type 4 Design Approach Channel, Type 2 Design Umbrella Supports

Elevation ft NGVD	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
26	1	1	1	-1	+2	+2	0.01	0.03	0.03	0	0	0
25	1	1	2	-1	+3	0	0.01	0.04	0.00	0	0	0
24	1	1	2	0	+3	0	0.00	0.04	0.00	0	0	0
23	1	1	1	-1	+2	0	0.01	0.03	0.00	0	0	0
22	1	2	2	-2	+2	0	0.03	0.03	0.00	0	0	0
21	1	1	2	-2	+3	0	0.03	0.04	0.00	0	0	0
20	1	1	2	-2	+2	+2	0.03	0.03	0.03	0	0	0
20	1	2	x	-1	+3	x	0.01	0.04	x	A	A	x
20	1	x	2	0	x	-3	0.00	x	0.04	A	x	A
20	x	2	2	x	-1	+3	x	0.01	0.04	x	A	A
20	1	x	x	-1	x	x	0.01	x	x	A	x	x
20	x	2	x	x	+1	x	x	0.01	x	x	A	x
20	x	x	2	x	x	-2	x	x	0.03	x	x	A

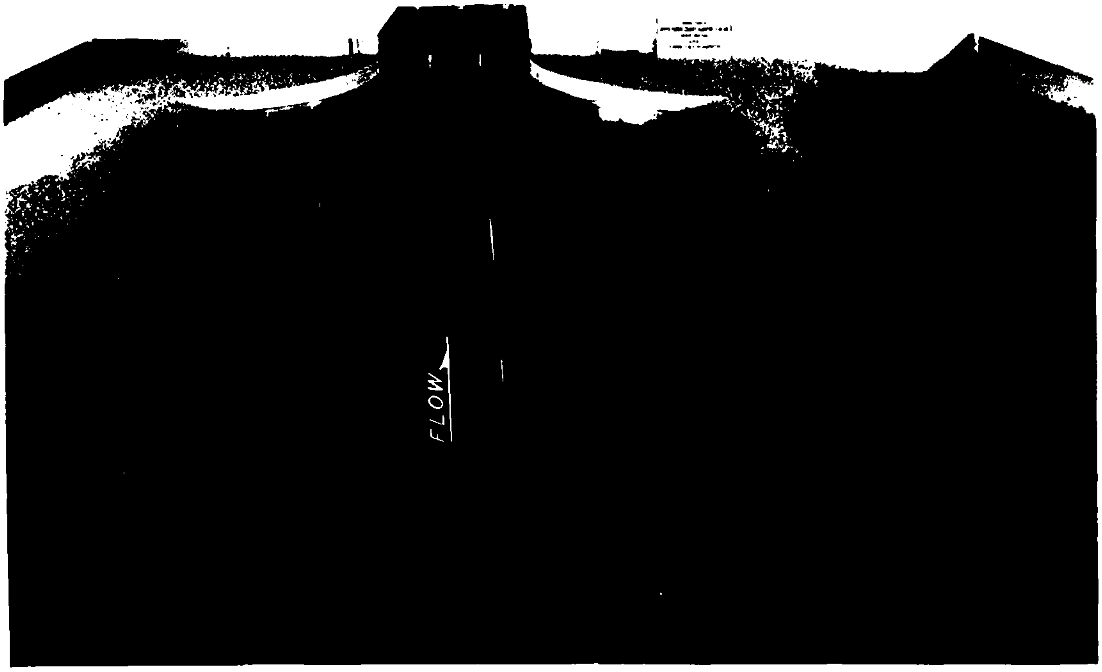
Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
Discharge 680 cfs per pump, temperature 80-87°F.
* See Figure 5, page 16, for explanation of A.

Table 32

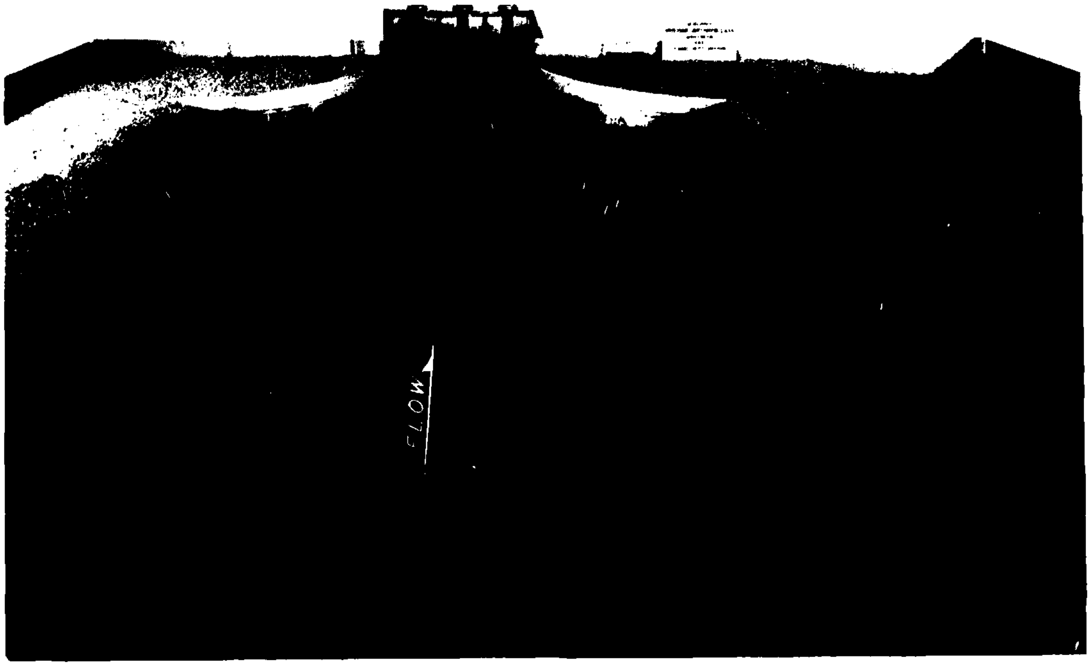
Sump Performance, Type 25 Design Sump, Type 3 Design Umbrella Supports, Type 1 Design Approach Channel

Elevation	Maximum Pressure Fluctuation Feet of Water			Swirl: Vortimeter Revolutions per Minute			Swirl: Rotational Flow Indicator			Vortex Development*		
ft NGVD	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3	Bay 1	Bay 2	Bay 3
32	1	1	1	-1	+2	+1	0.01	0.03	0.01	C	C	C
31	1	1	1	-1	+1	0	0.01	0.01	0.00	C	C	C
30	1	1	1	0	+1	0	0.00	0.01	0.00	C	C	C
29	1	1	1	-1	+1	+1	0.01	0.01	0.01	C	C	C
28	1	1	1	0	+2	+1	0.00	0.03	0.01	C	C	C
27	1	1	1	0	+2	+1	0.00	0.03	0.01	0	0	0
19	x	x	2	x	x	-4	x	x	0.05	x	x	A
18	x	x	1	x	x	-7	x	x	0.09	x	x	A
17	x	x	6	x	x	-34	x	x	0.44	x	x	B-FV
16	x	x	16	x	x	**	x	x	**	x	x	B-FV

Note: x = pump not operating; - = swirl counterclockwise; + = swirl clockwise; and ± = swirl direction intermittent.
FV = floor vortex.
Discharge 613 cfs per pump.
* See Figure 5, page 16, for explanation of A, B, and C.
** Vortimeter rotating too fast to count.

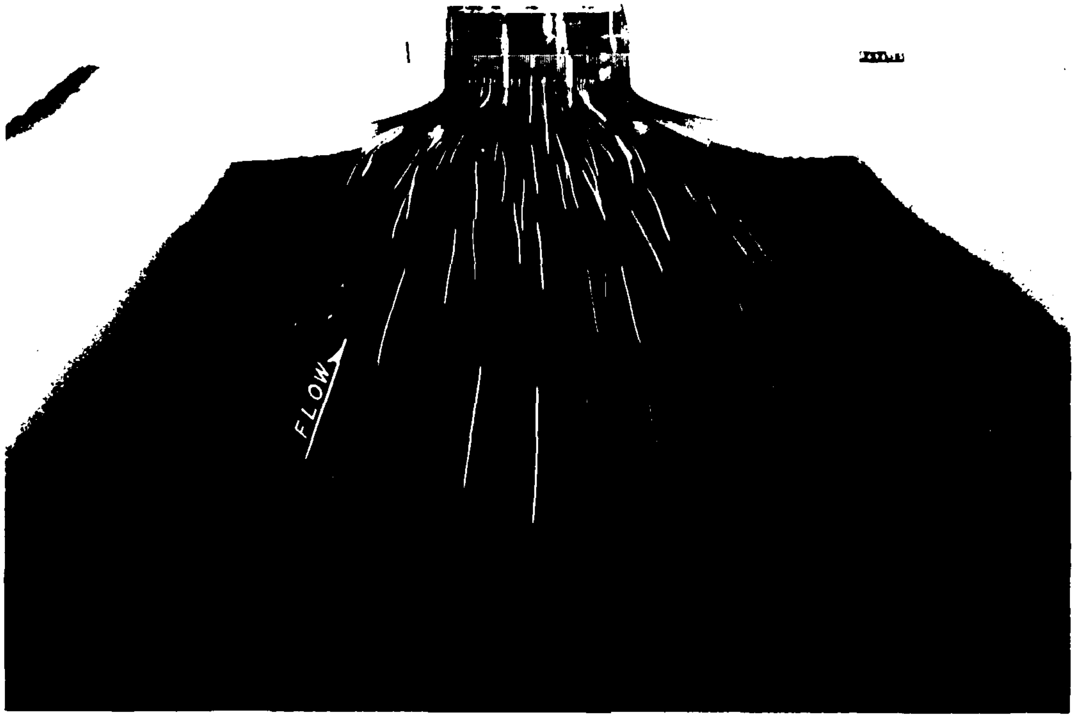


a. Water-surface el 20.0, three pumps operating

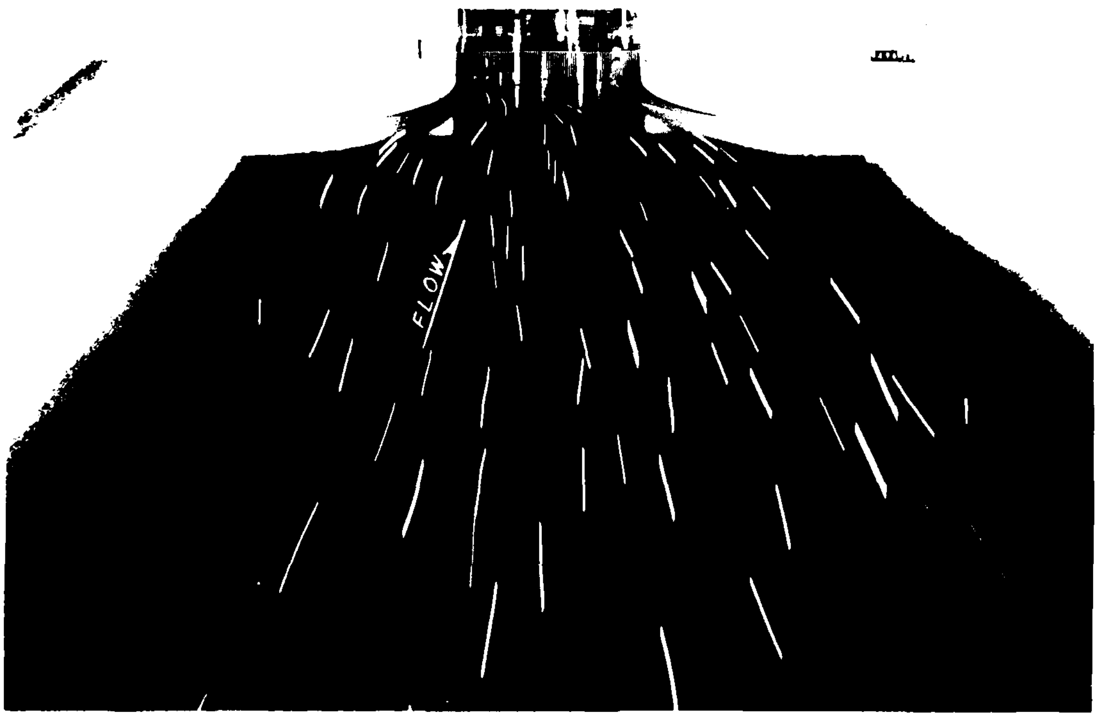


b. Water-surface el 20.0, pump 1 operating

Photo 1. Flow conditions with type 1 (original) approach channel



a. Water-surface el 20.0, three pumps operating



b. Water-surface el 20.0, pump 1 operating

Photo 2. Flow conditions with type 3 design approach channel

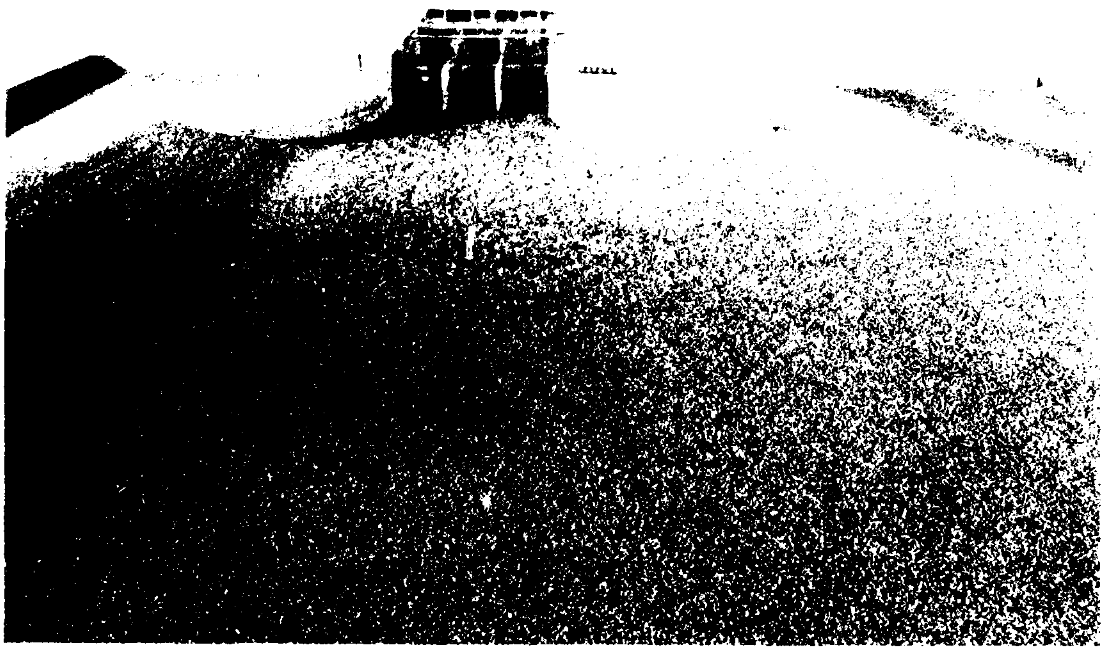
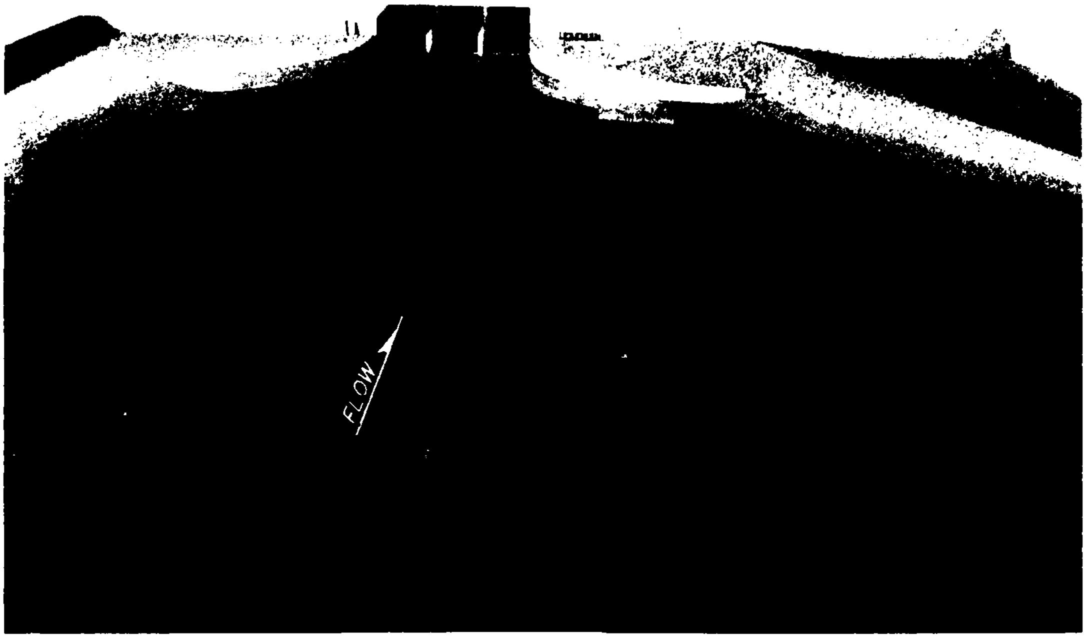
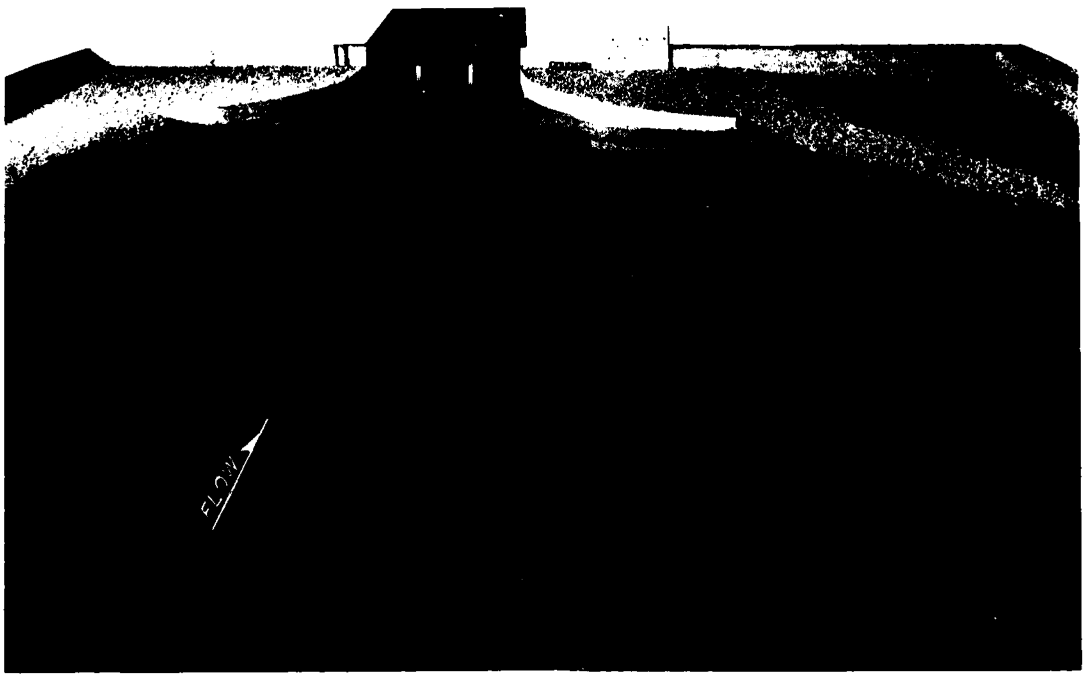


Photo 3. Type 4 design approach channel

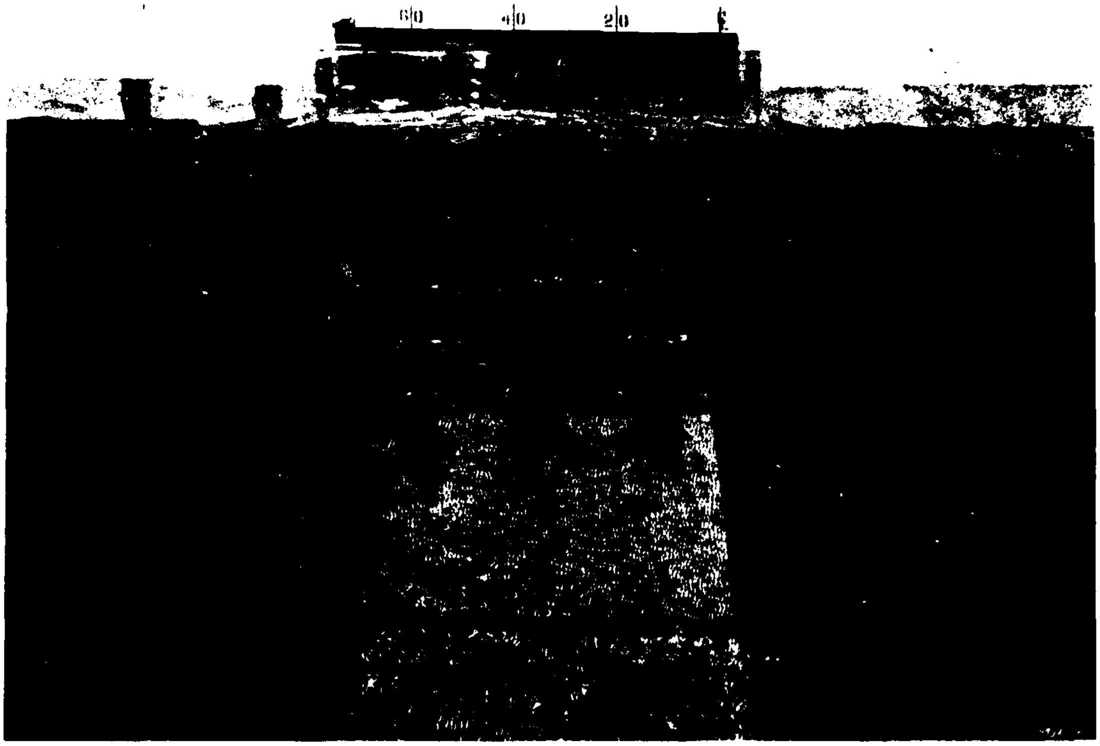


a. Water-surface el 20.0, three pumps operating

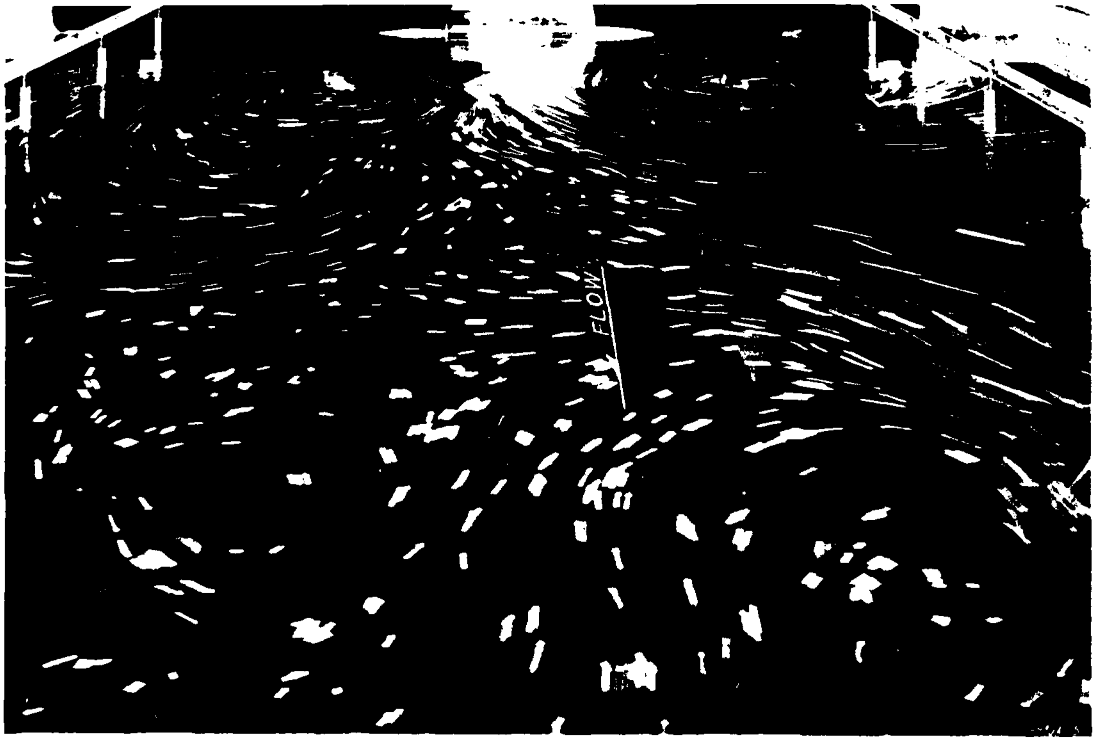


b. Water-surface el 20.0, pump 1 operating

Photo 4. Flow conditions with type 4 design approach channel



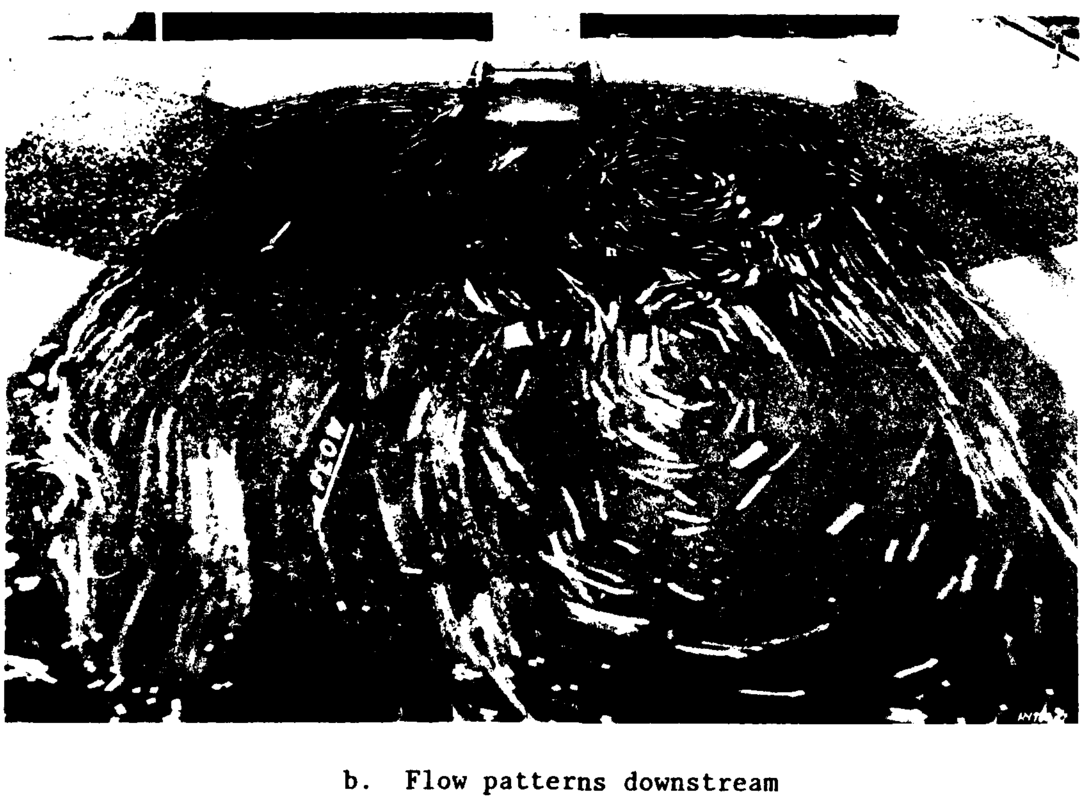
a. Conditions in stilling basin



b. Flow patterns downstream

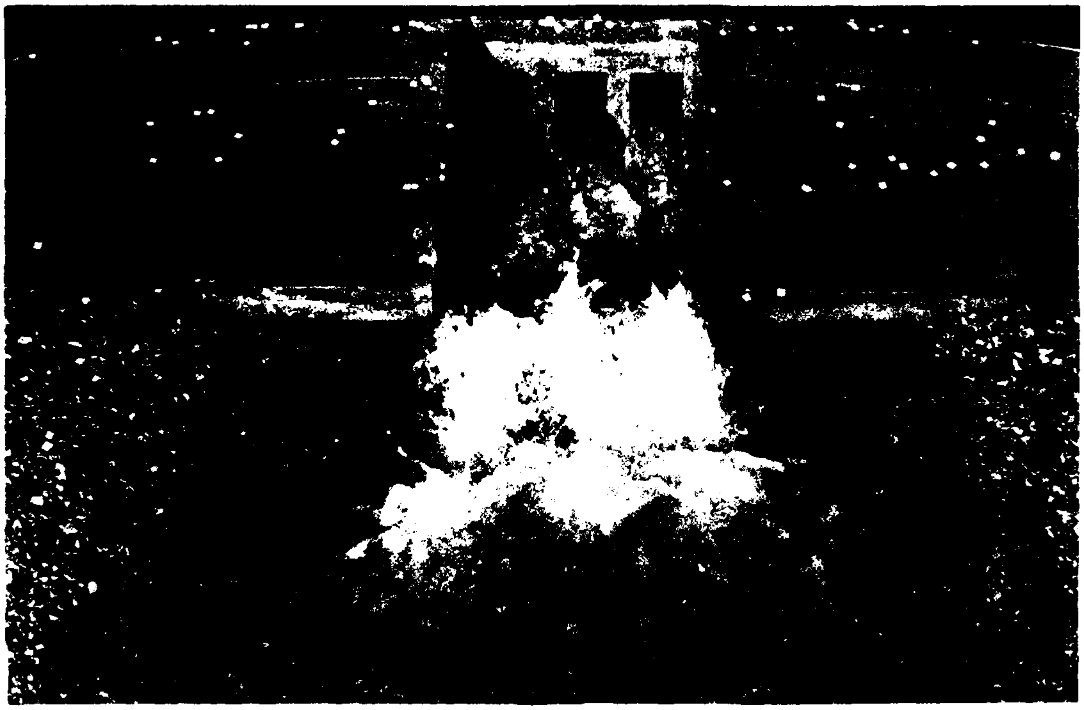
Photo 5. Type 1 design stilling basin; tailwater el 46.0, discharge 613 cfs per pump, three pumps operating

a. Conditions in stilling basin

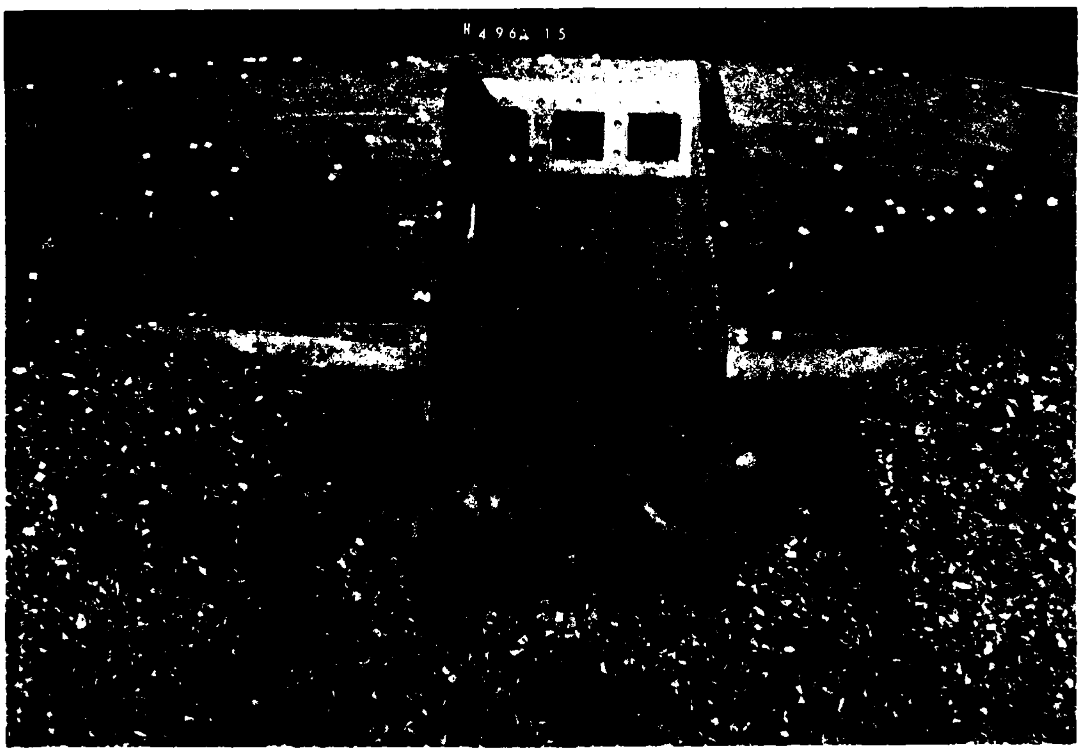


b. Flow patterns downstream

Photo 6. Type 1 design stilling basin; tailwater el 18.8, discharge 613 cfs per pump, three pumps operating



a. Conditions in stilling basin



b. Riprap failure

Photo 7. Type 1 design stilling basin; tailwater el 3.1, discharge 613 cfs per pump, three pumps operating

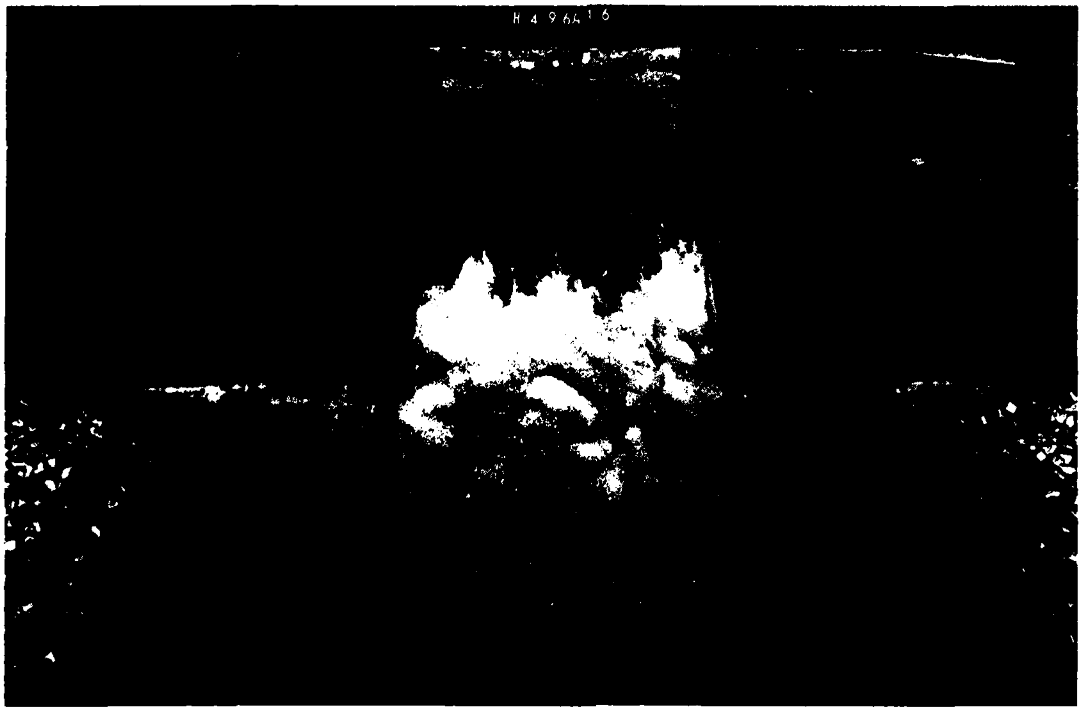


Photo 8. Type 3 design stilling basin; tailwater el 3.1, discharge 613 cfs per pump, three pumps operating

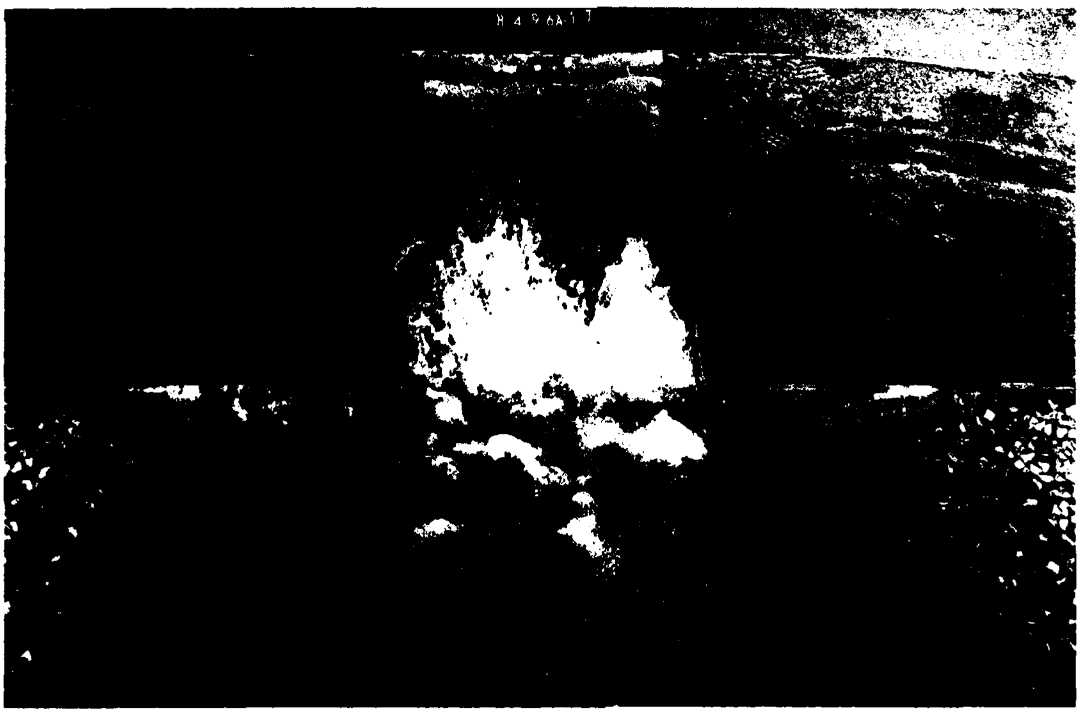


Photo 9. Type 3 design stilling basin; tailwater el 3.1, discharge 613 cfs per pump, two pumps operating

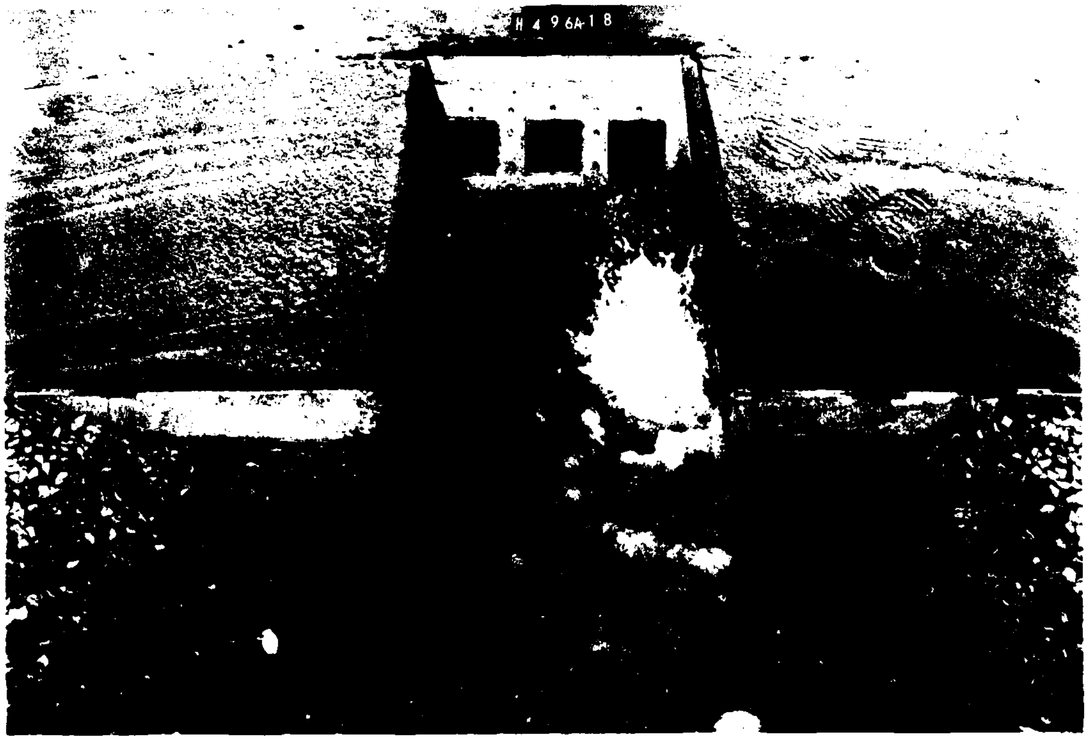


Photo 10. Type 3 design stilling basin; tailwater el 3.1, discharge 613 cfs, one pump operating

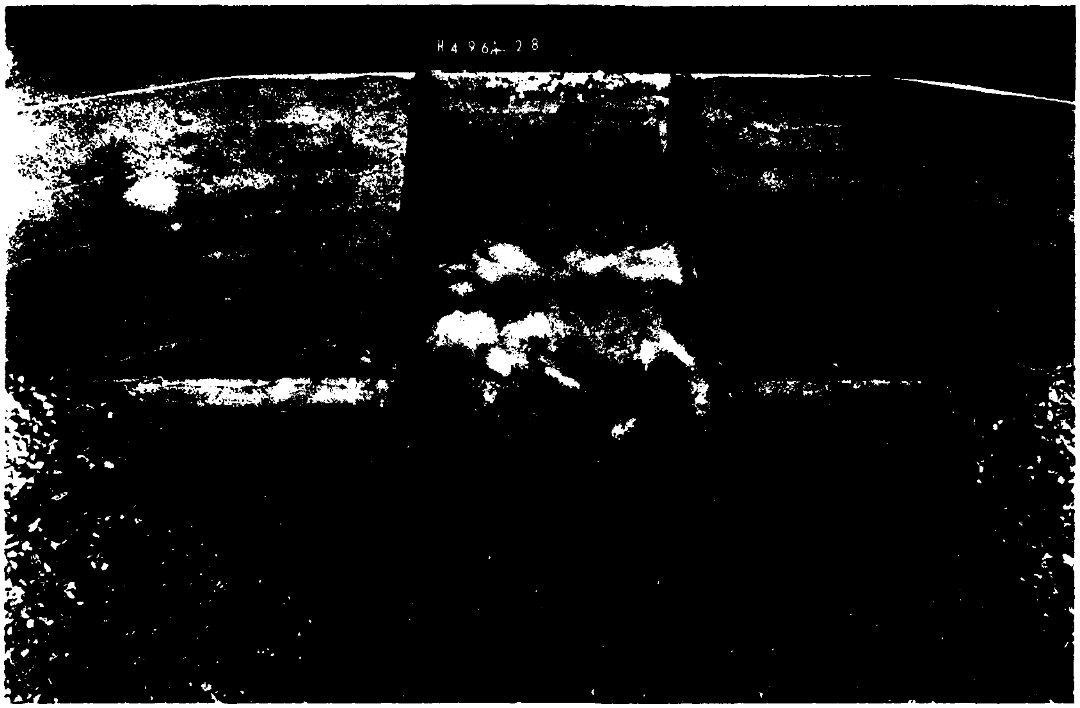


Photo 11. Type 4 design stilling basin; tailwater el 3.1, discharge 613 cfs per pump, three pumps operating

Photo 12. Type 4 design stilling basin; tailwater el 3.1, discharge 613 cfs per pump, two pumps operating

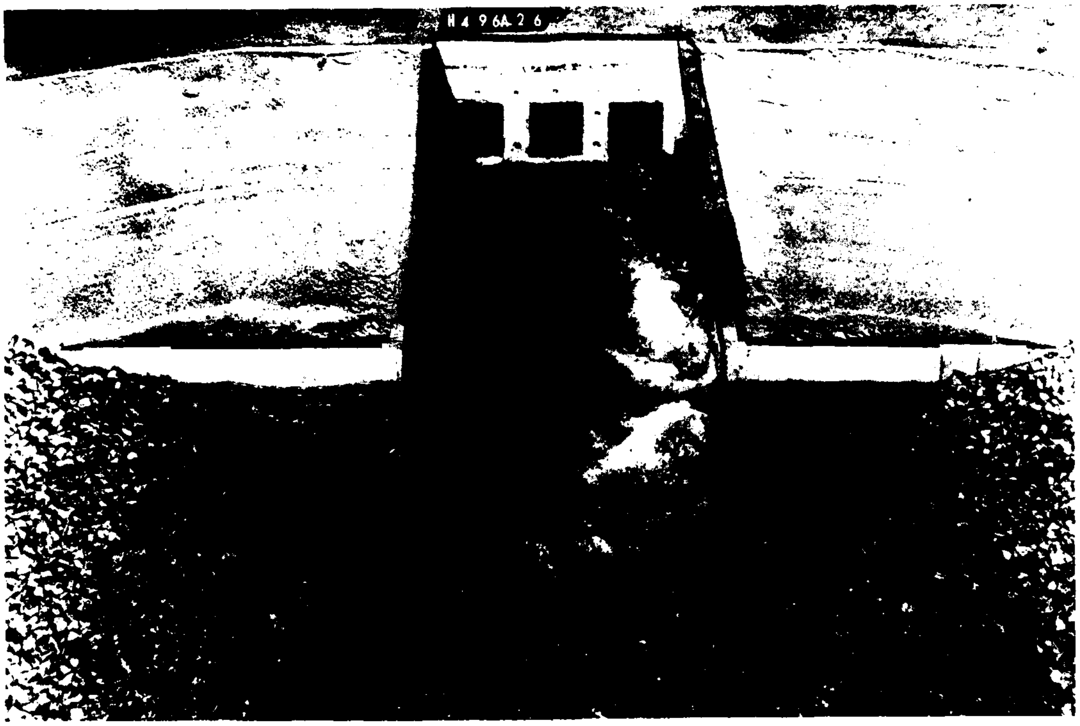


Photo 13. Type 4 design stilling basin; tailwater el 3.1, discharge 613 cfs, one pump operating

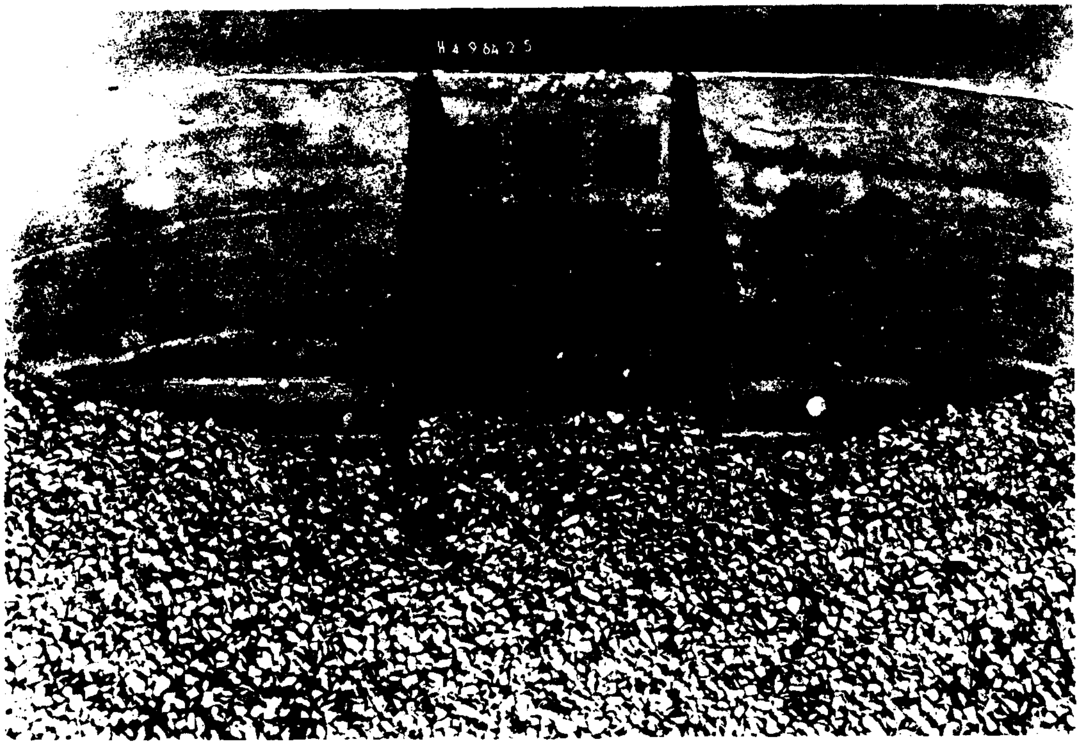
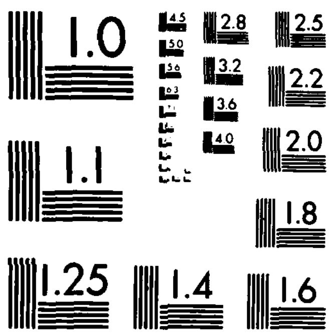


Photo 14. Type 4 stilling basin; riprap failure and rock deposition after single pump operating; tailwater el 3.1, discharge 613 cfs

AD-A128 517 POINTE COUPEE PUMPING STATION SUMP AND OUTLET STRUCTURE 2/2
UPPER POINTE COUP..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS HYDRA.. R R COPELAND
UNCLASSIFIED MAR 83 WES/TR/HL-83-3 F/G 13/3 NL


1.0
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1.6

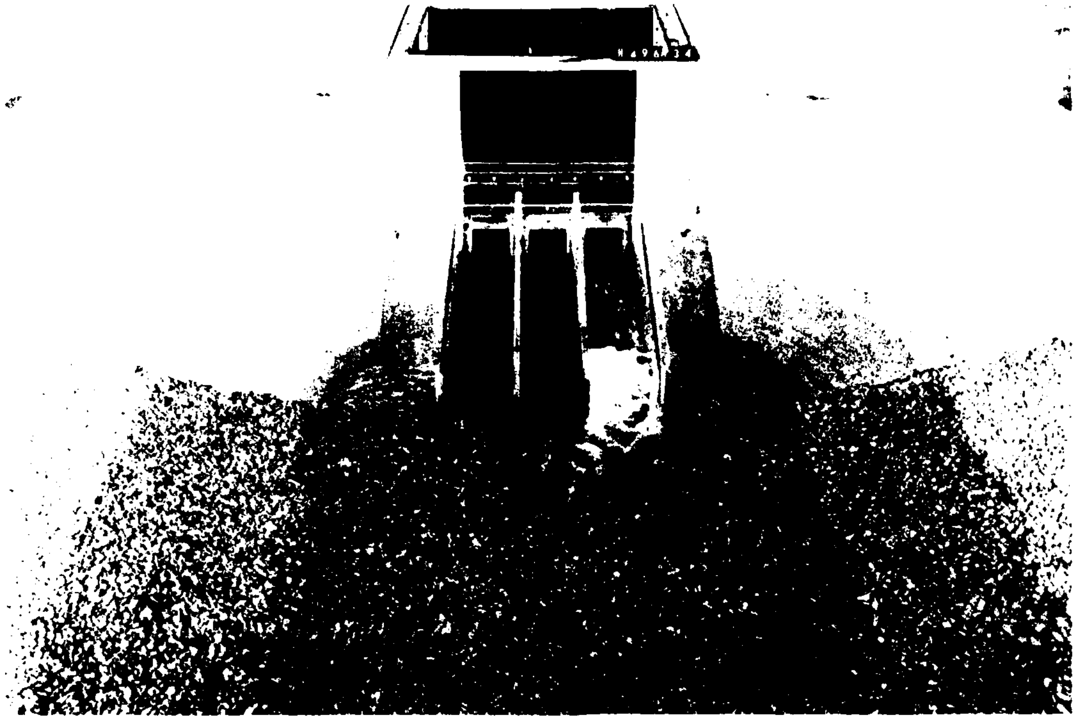


Photo 15. Type 8 design stilling basin; tailwater el 3.1, discharge 680 cfs, one pump operating

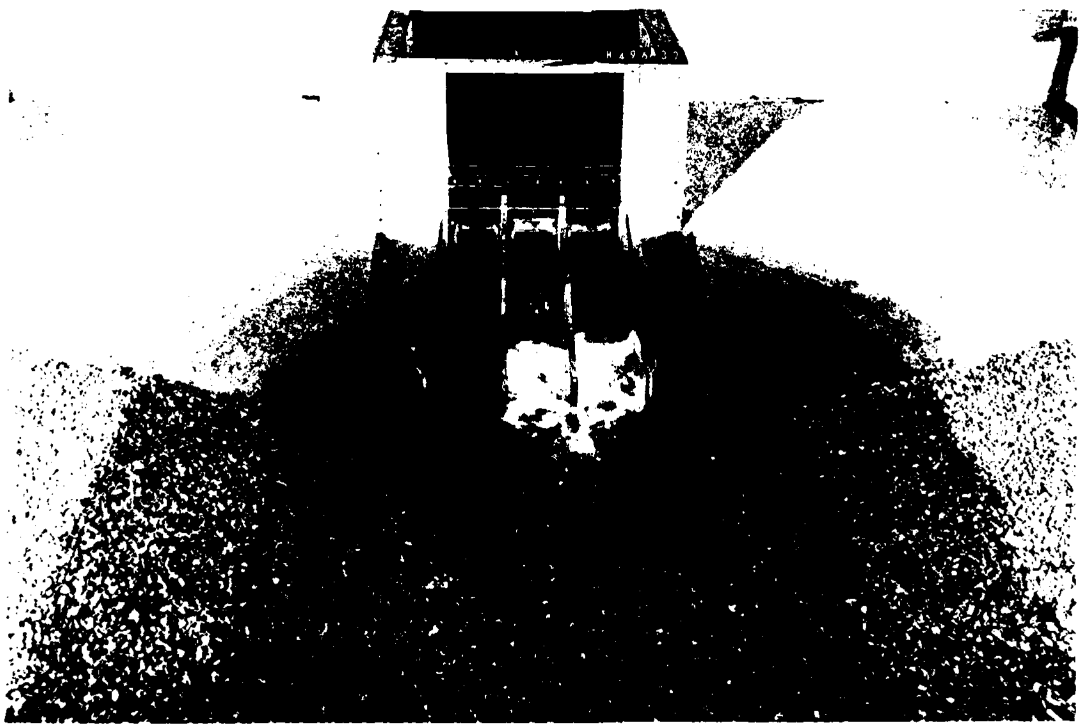


Photo 16. Type 8 design stilling basin; tailwater el 3.1, discharge 680 cfs per pump, two pumps operating

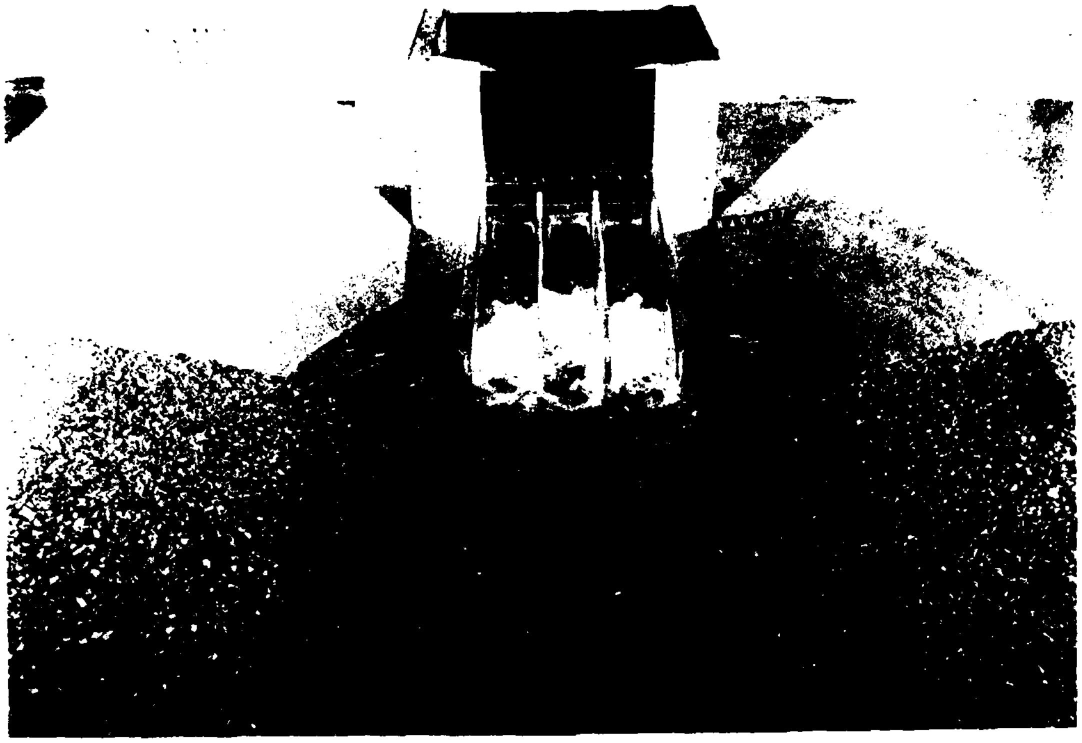


Photo 17. Type 8 design stilling basin; tailwater el 3.1, discharge 680 cfs per pump; three pumps operating

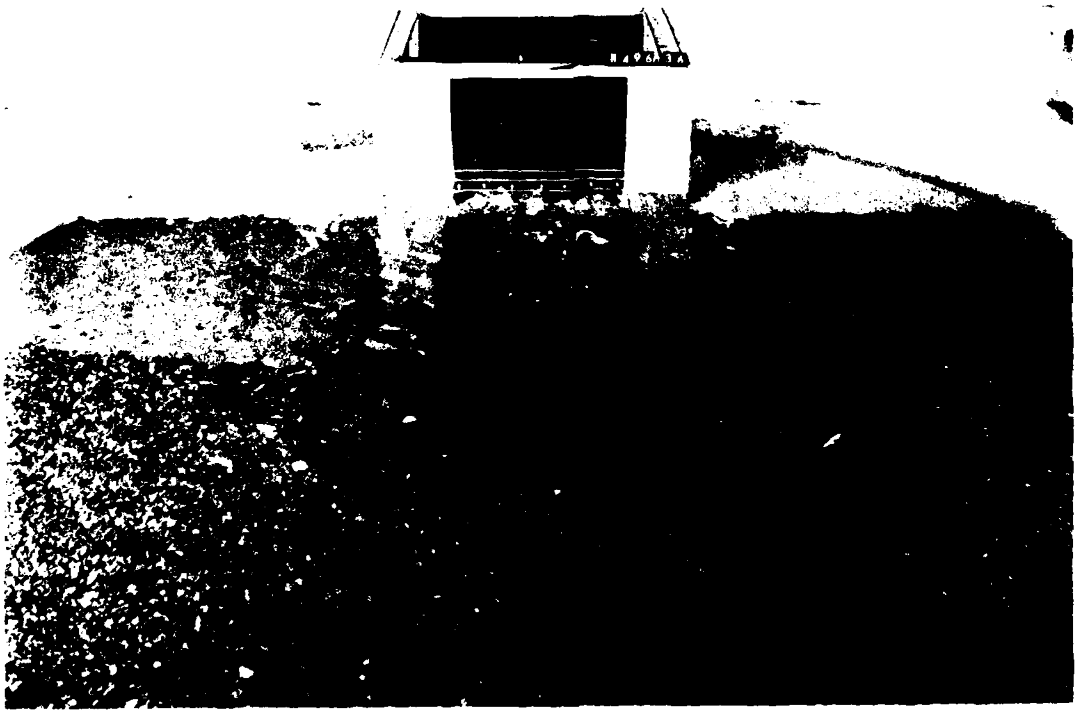
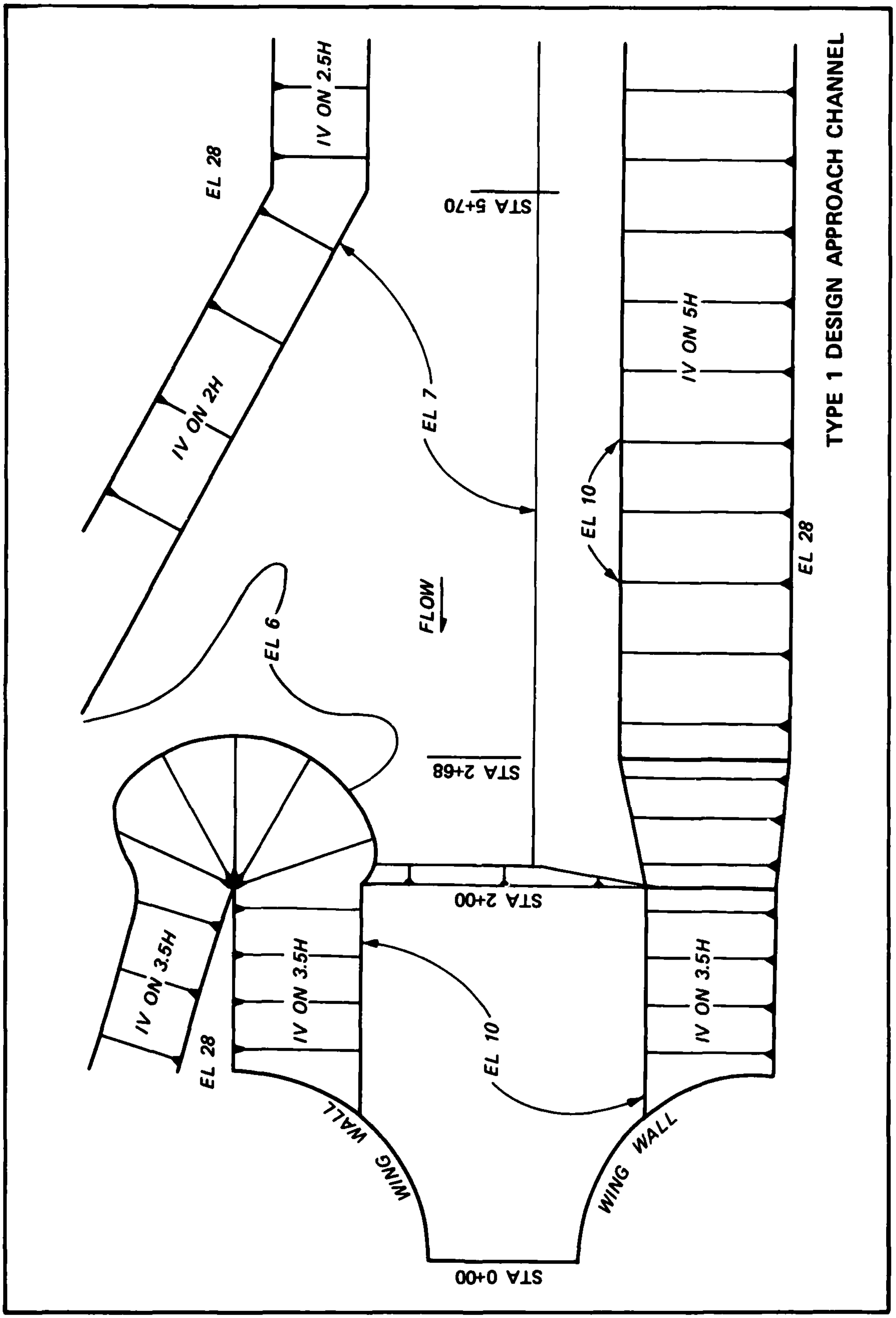
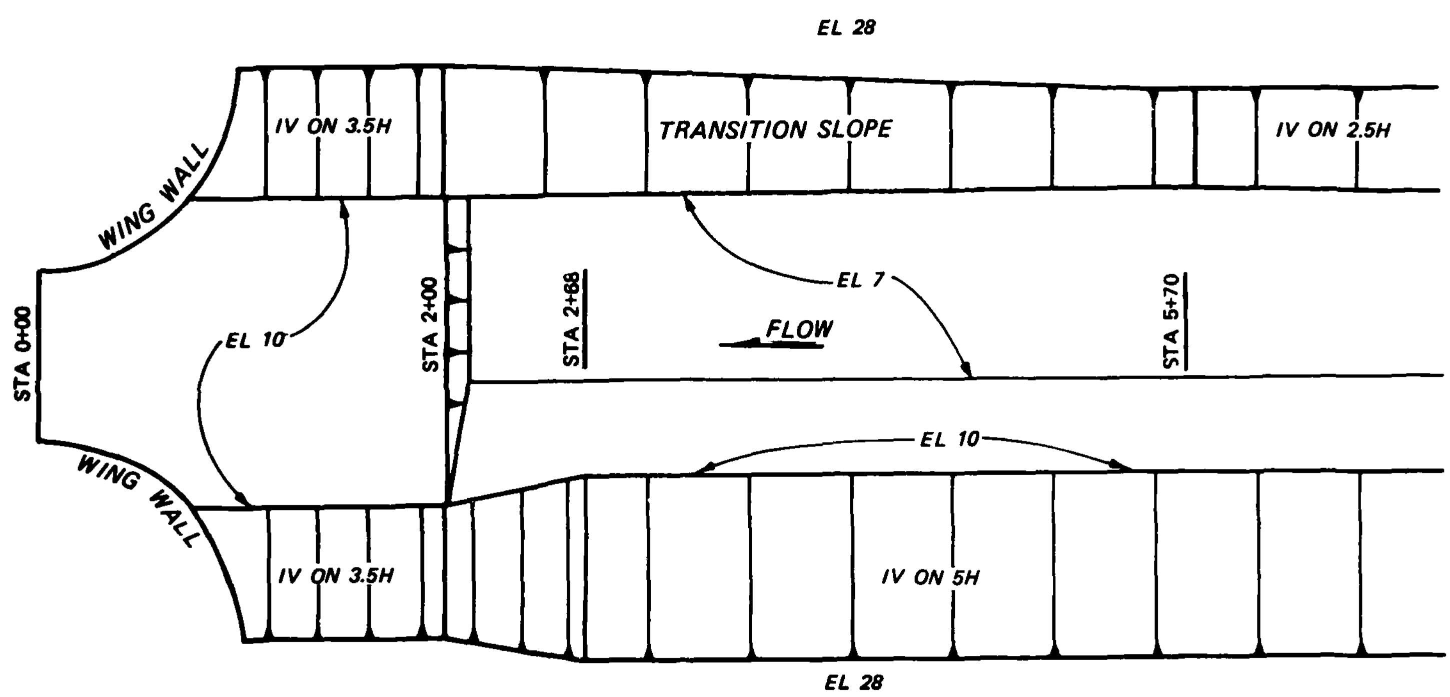


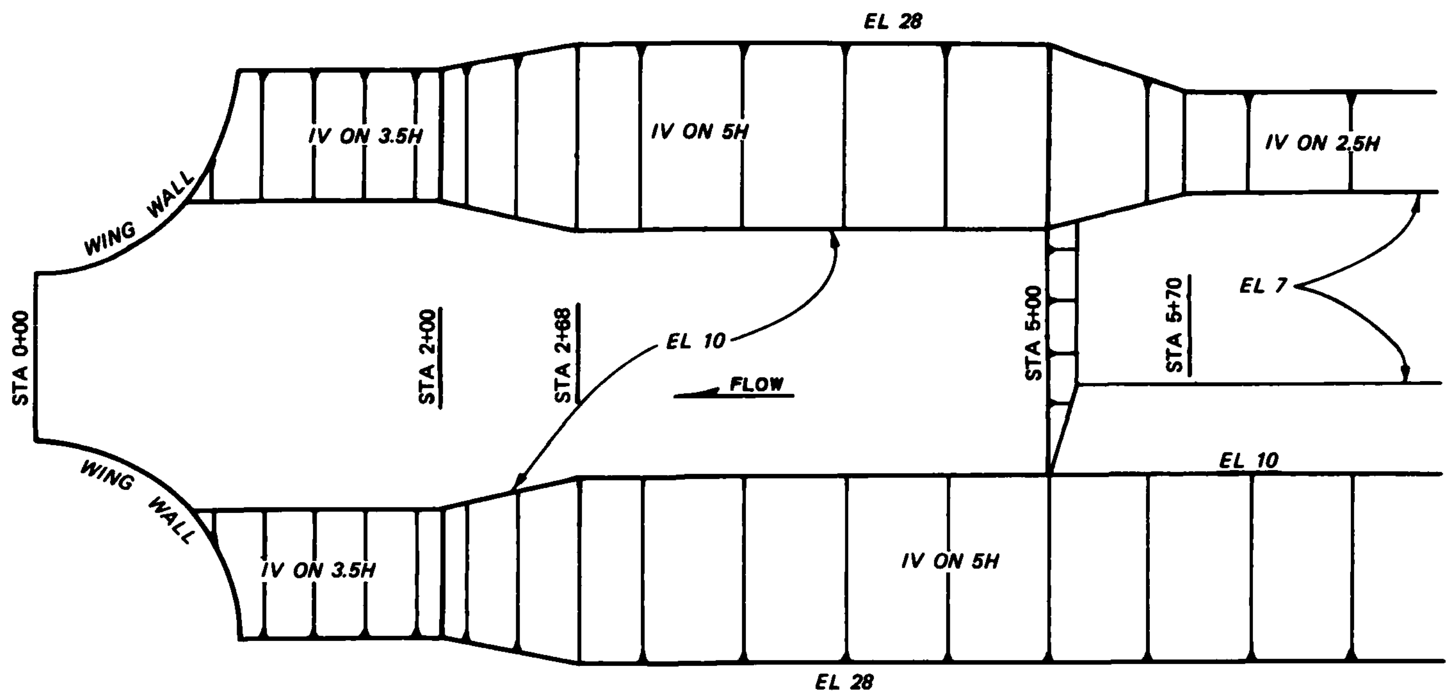
Photo 18. Type 8 design stilling basin; tailwater el 18.8, discharge 680 cfs per pump, three pumps operating



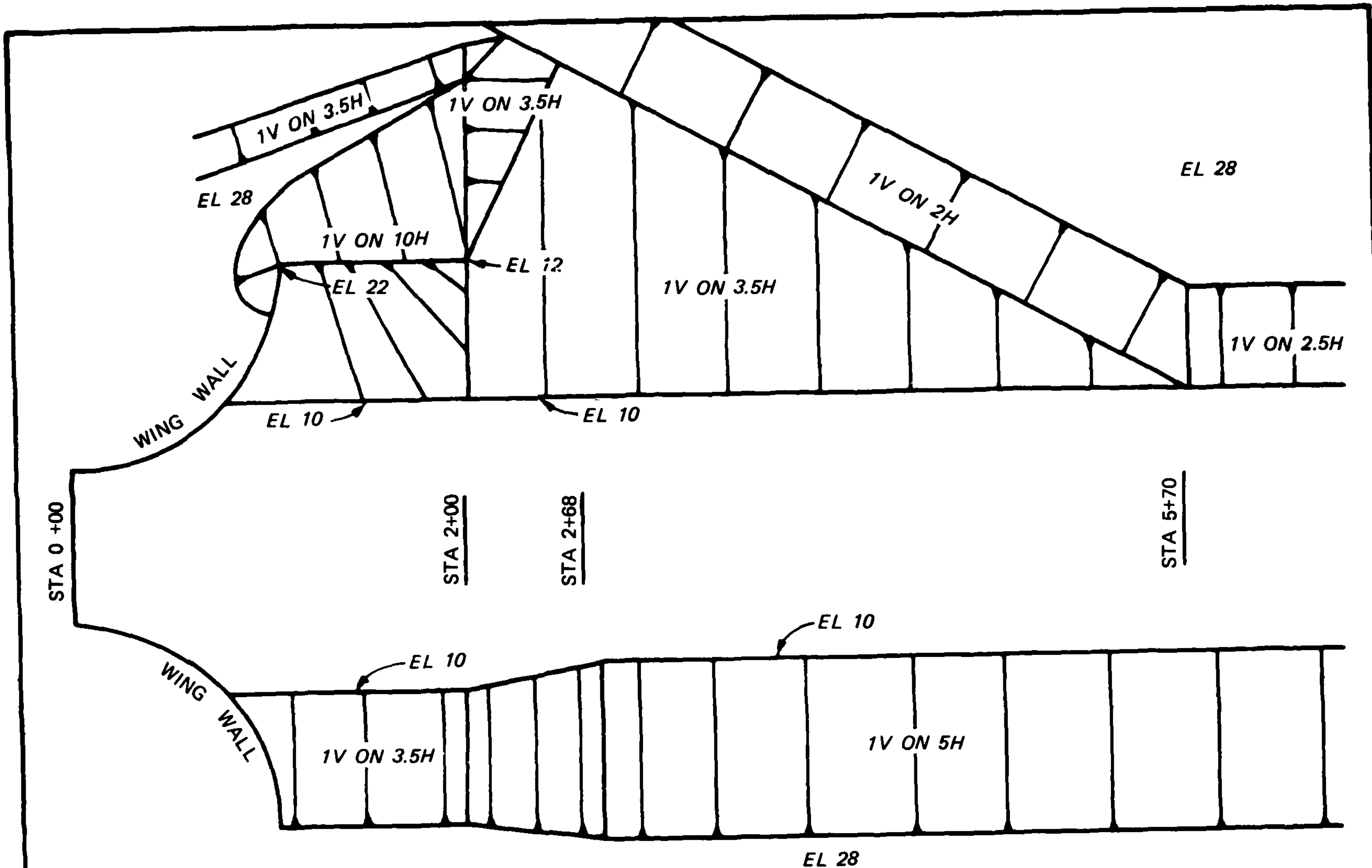
TYPE 1 DESIGN APPROACH CHANNEL



TYPE 2 DESIGN APPROACH CHANNEL

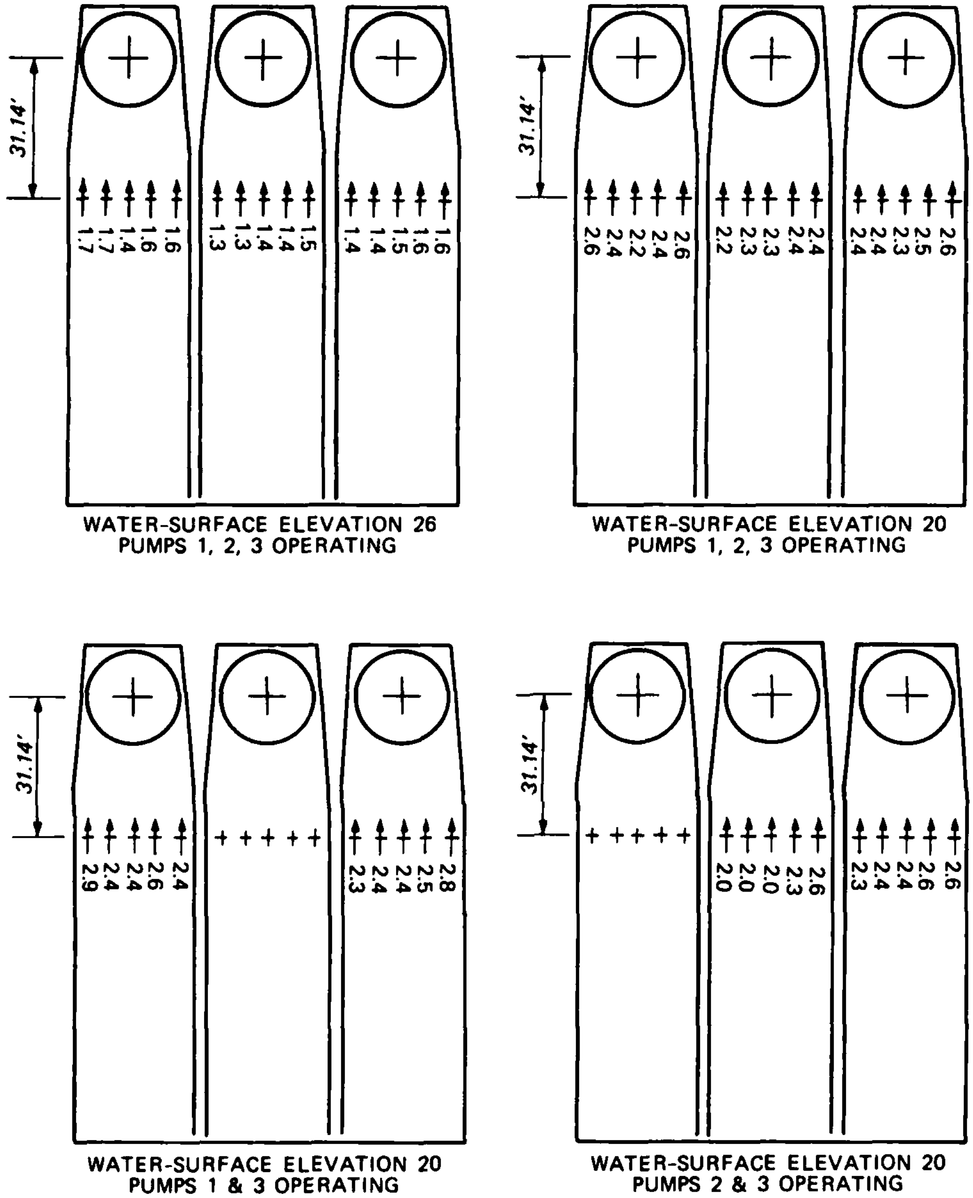


TYPE 3 DESIGN APPROACH CHANNEL



TYPE 4 DESIGN APPROACH CHANNEL

PLATE 4



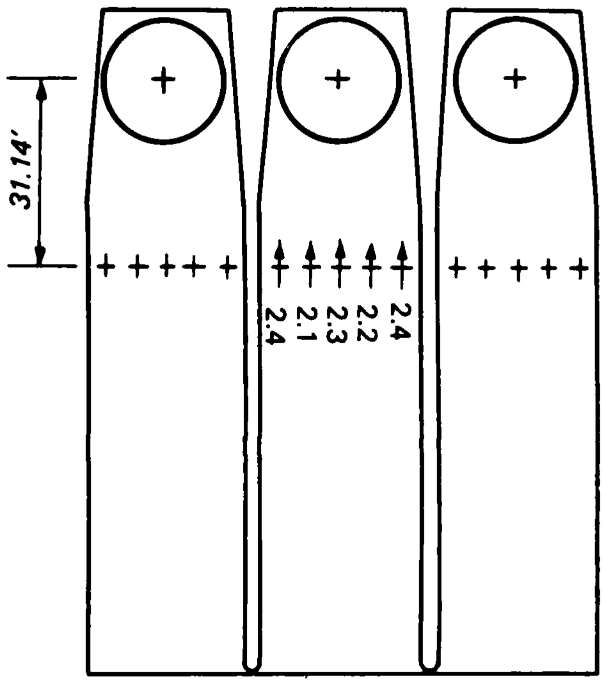
NOTE: Velocities (fps) are 3.5 ft above floor
Discharge 588 cfs per pump

SUMP VELOCITIES

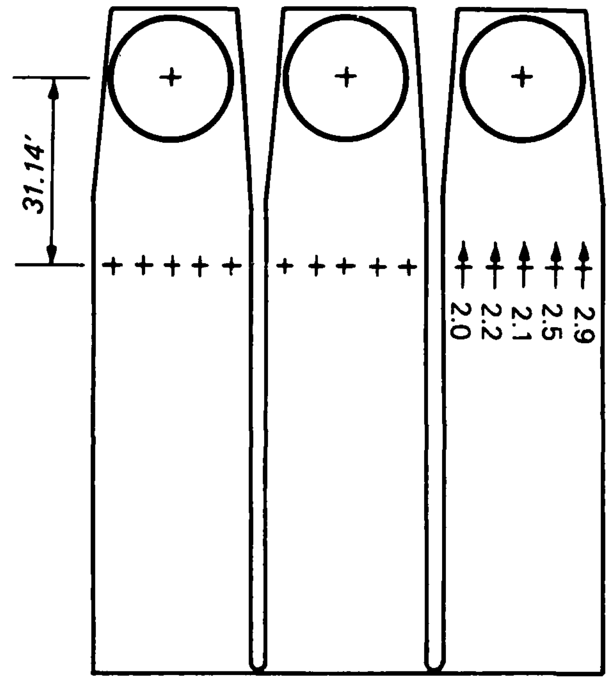
TYPE 25 DESIGN SUMP

TYPE 2 DESIGN UMBRELLA SUPPORTS

TYPE 1 DESIGN APPROACH CHANNEL



WATER-SURFACE ELEVATION 20
PUMP 2 OPERATING

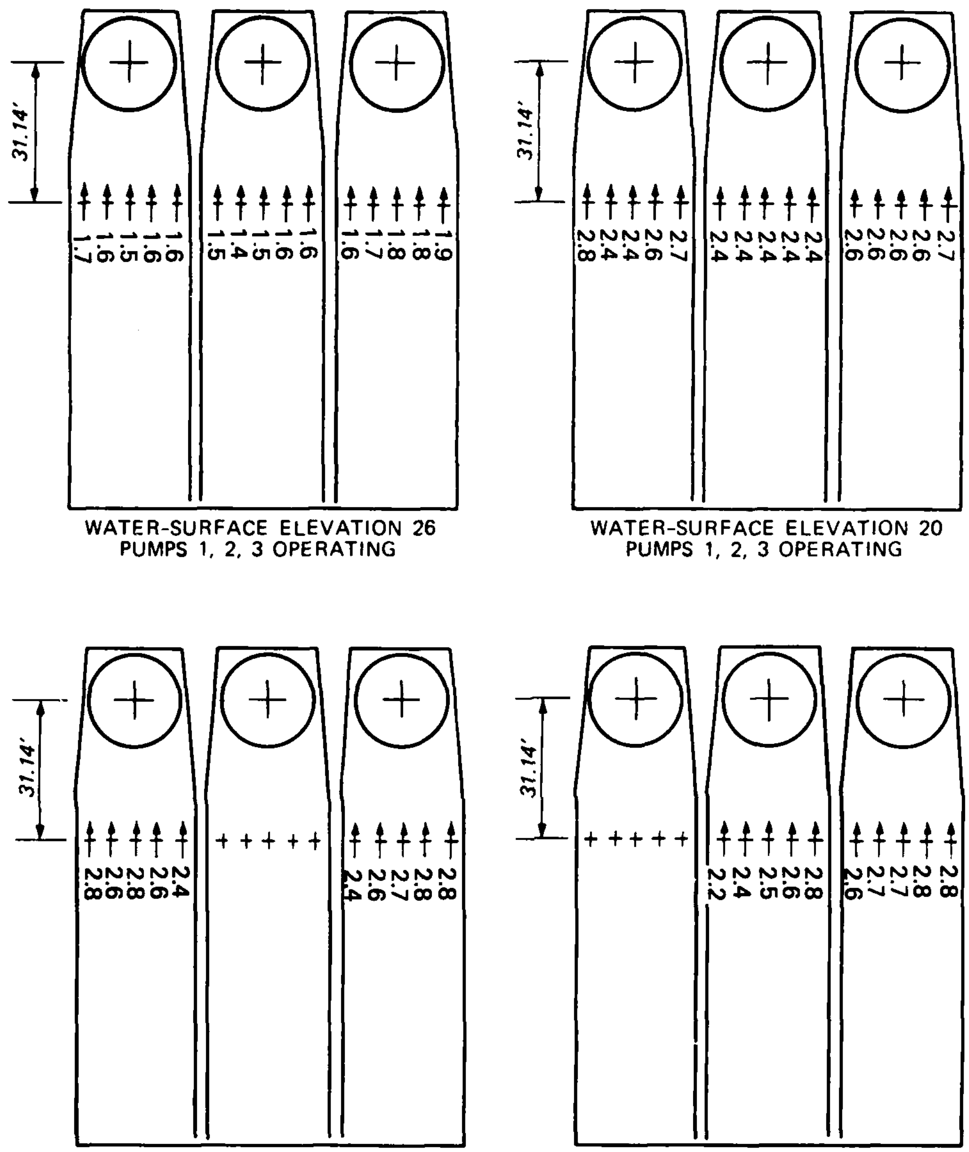


WATER-SURFACE ELEVATION 20
PUMP 3 OPERATING

NOTE: Velocities (fps) are 3.5 ft above floor
Discharge 588 cfs per pump

SUMP VELOCITIES

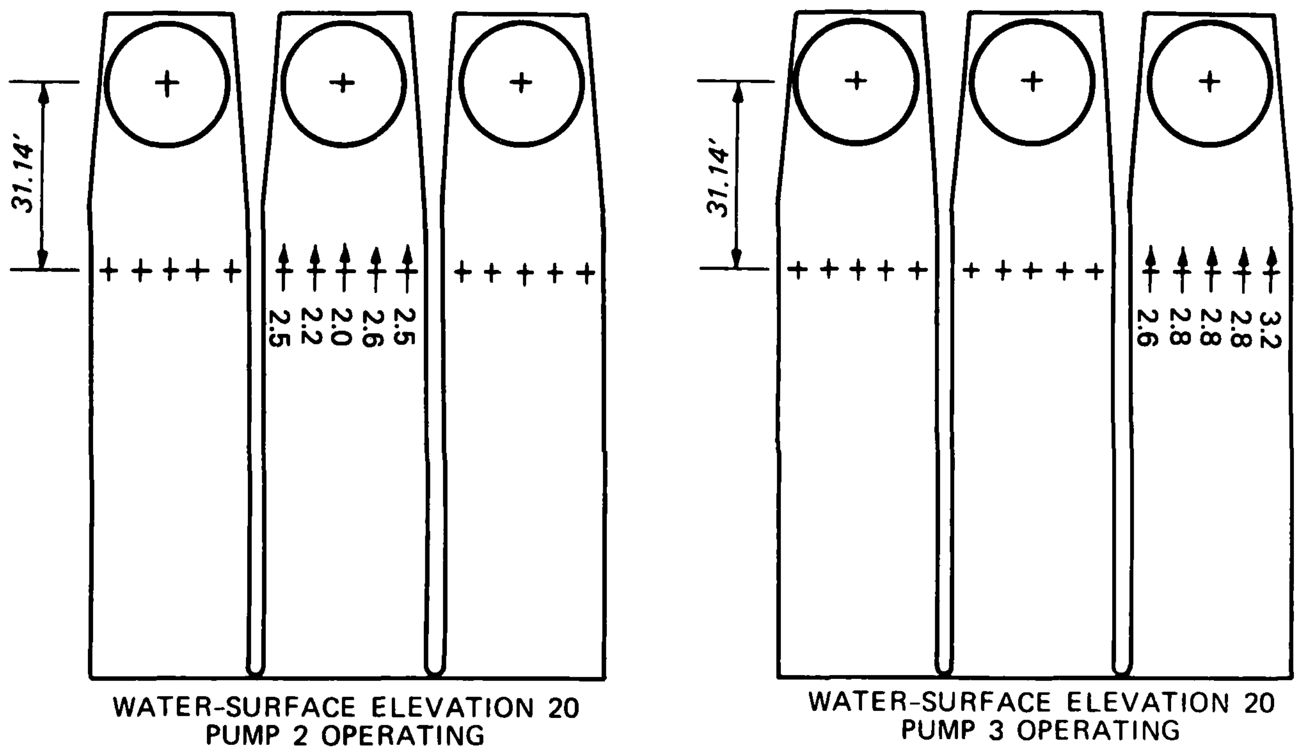
TYPE 25 DESIGN SUMP
TYPE 2 DESIGN UMBRELLA SUPPORTS
TYPE 1 DESIGN APPROACH CHANNEL



NOTE: Velocities (fps) are 3.5 ft above floor
Discharge 588 cfs per pump

SUMP VELOCITIES

TYPE 28 DESIGN SUMP
TYPE 2 DESIGN UMBRELLA SUPPORTS
TYPE 4 DESIGN APPROACH CHANNEL
VARIOUS PUMPS OPERATING



NOTE: Velocities (fps) are 3.5 ft above floor.
Discharge 588 cfs per pump.

SUMP VELOCITIES

TYPE 28 DESIGN SUMP
TYPE 2 DESIGN UMBRELLA SUPPORTS
TYPE 4 DESIGN APPROACH CHANNEL

PLATE 8

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Copeland, Ronald R.
  Pointe Coupee pumping station sump and outlet structure, Upper Pointe Coupee Loop Area, Louisiana : Hydraulic Model Investigation / by Ronald R. Copeland (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. ; available from NTIS, 1983.
  94 p. in various pagings, 8 p. of plates : ill. ; 27 cm. -- (Technical report ; HL-83-3)
  Cover title.
  "March 1983."
  Final report.
  "Prepared for U.S. Army Engineer District, New Orleans."

  1. Hydraulic models. 2. Pumping stations. 3. Stilling basins. I. United States. Army. Corps of Engineers. New Orleans District. II. U.S. Army Engineer Waterways

Copeland, Ronald R.
  Pointe Coupee pumping station sump and outlet : ... 1983.
(Card 2)

Experiment Station. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-83-3.
TA7.W34 no.HL-83-3

END

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